NIST-GCR-98-754

Determination of Properties and the Prediction of the Energy Release Rate of Materials in the ISO 9705 Room-Corner Test. Appendices.

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United States Department of Commerce
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Gaithersburg, MD 20899

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Notice

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DETERMINATION OF PROPERTIES AND THE PREDICTION OF THE ENERGY RELEASE RATE OF MATERIALS IN THE ISO 9705 ROOM-CORNER TEST.

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INTERIM REPORT
APPENDICES

June, 1998

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Laboratory of Building and Fire Research
Washington, D.C. 20234

APPENDICES

Appendix A – LSF Cone Calorimeter Data

- A.1 Nomenclature
- A.2 Cone Calorimeter Data
- A.3 Ignition Data
- A.4 Heat of Combustion Data
- A.5 Heat of Gasification Data
- A.6 Total Energy per Unit Area

A.1 — Nomenclature

Due to limitations in the presentation of the Cone Calorimeter data used, the following nomenclature shall apply to all tables and charts contained in this Appendix. All sample materials were tested 20 times with the cone calorimeter--exposure of 5 samples to 25, 35, 40 and 50 kW/m^2 external radiant heat fluxes. However not all samples ignited and only the values for materials that did ignite are presented in the following tables and graphs. The three average heat of combustion values represent a numerical average of the values obtained for specimens that ignited during testing. The following "symbols" are used to represent the actual physical values and have the units listed:

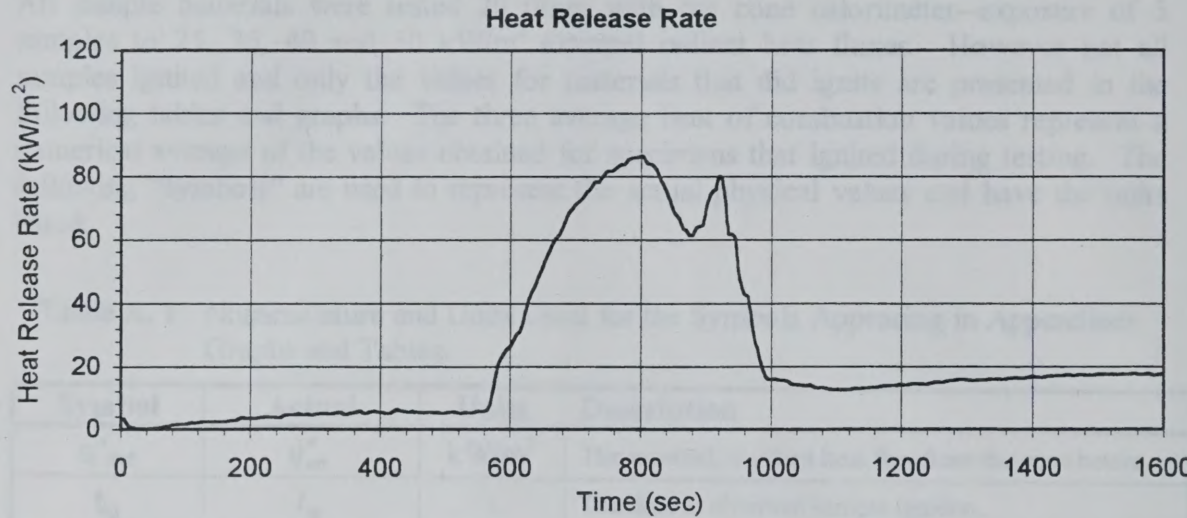
Table A. 1: Nomenclature and Units Used for the Symbols Appearing in Appendices Graphs and Tables.

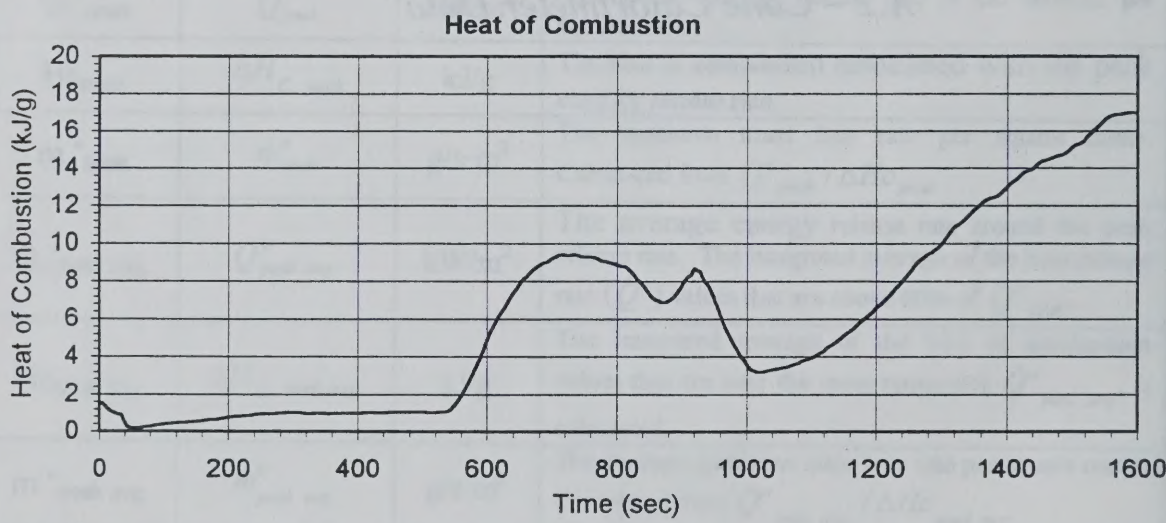
Symbol	Actual	Units	Description
q"ext	$\dot{q}''_{ext.}$	kW/m^2	The external, incident heat flux from the cone heater.
tig	t_{ig}	s	The time to observed sample ignition.
Q."peak	$\dot{Q}''_{peak}$	kW/m^2	The peak energy release rate of the material per square meter.
Hcpeak	$\Delta H_{C,\ peak}$	kJ/g	The heat of combustion associated with the peak energy release rate.
m."peak	$\dot{m}''_{peak}$	g/s·m^2	The specimen mass loss rate per square meter. Calculated from $\dot{Q}''_{peak} / \Delta Hc_{peak}$
Q."peak avg.	$\dot{Q}''_{peak\ avg.}$	kW/m^2	The average energy release rate around the peak release rate. The integrated average of the heat release rate ($\dot{Q}''$) values that are above 80% of $\dot{Q}''_{peak}$.
Hcpeak avg.	$\Delta H_{C,\ peak\ avg.}$	kJ/g	The integrated average of the heat of combustion values that are over the same range that $\dot{Q}''_{peak\ avg.}$ is calculated.
m."peak avg.	$\dot{m}''_{peak\ avg.}$	g/s·m^2	The average specimen mass loss rate per square meter. Calculated from $\dot{Q}''_{peak\ avg.} / \Delta Hc_{peak\ avg.}$
-dm/dt	$-dm/dt$	g/s	The negative value of the slope through the specimen mass vs. time curve based on the region of actual burning.
Q."overall avg.	$\dot{Q}''_{overall\ avg.}$	kW/m^2	The overall energy release rate of the material per square meter: $\Delta H_{C,\ overall\ avg.} \cdot \dot{m}''_{oveall\ avg.}$
Hcoverall avg.	$\Delta H_{C,\ overall\ avg.}$	kJ/g	The overall heat of combustion for the specimen. Based on the total energy evolved divided by the total mass loss.
m."overall avg.	$\dot{m}''_{overall\ avg.}$	g/s·m^2	The overall specimen mass loss rate per square meter. Calculated from $(-dm/dt)/A_{sample}$, where A_{sample} = 0.0088 m^2.

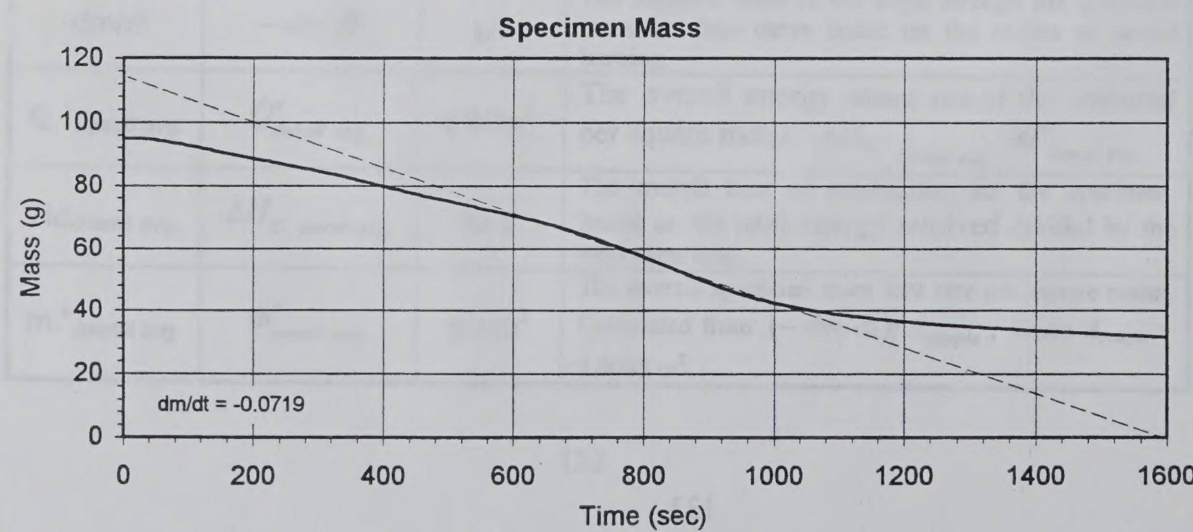
A.2 – Cone Calorimeter Data

Cone Calorimeter Data R 4.01 F.R. Chipboard

$35\ kW/m^2$, Test #1







Cone Calorimeter Data R 4.01 F.R. Chipboard
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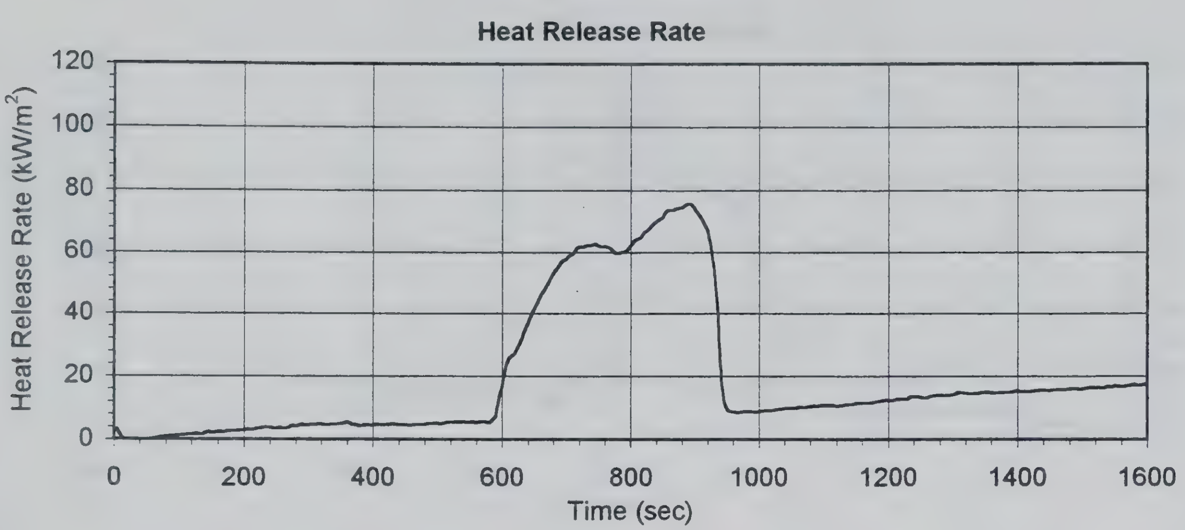

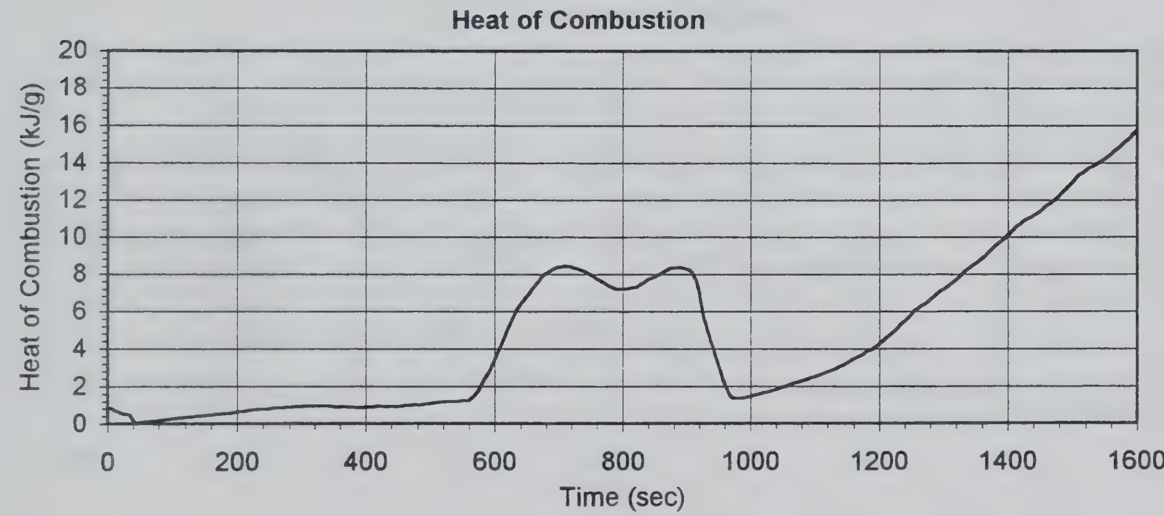

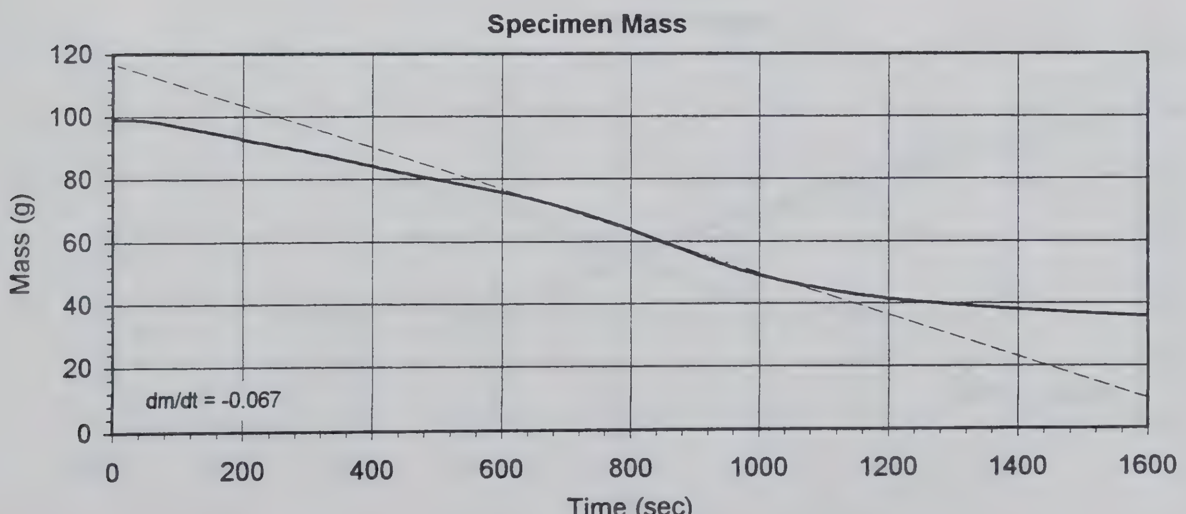

Cone Calorimeter Data R 4.01 F.R. Chipboard

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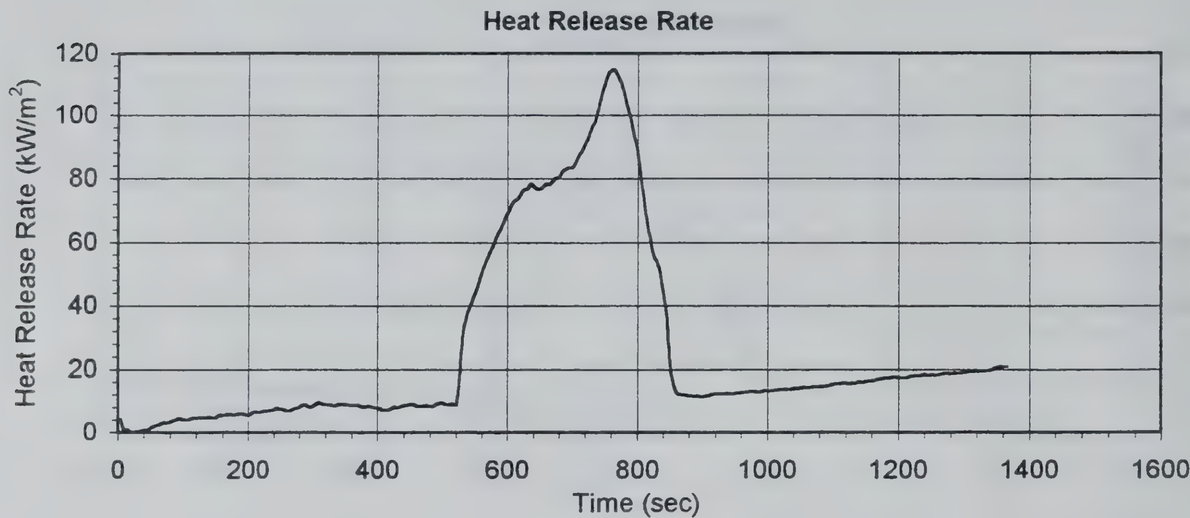
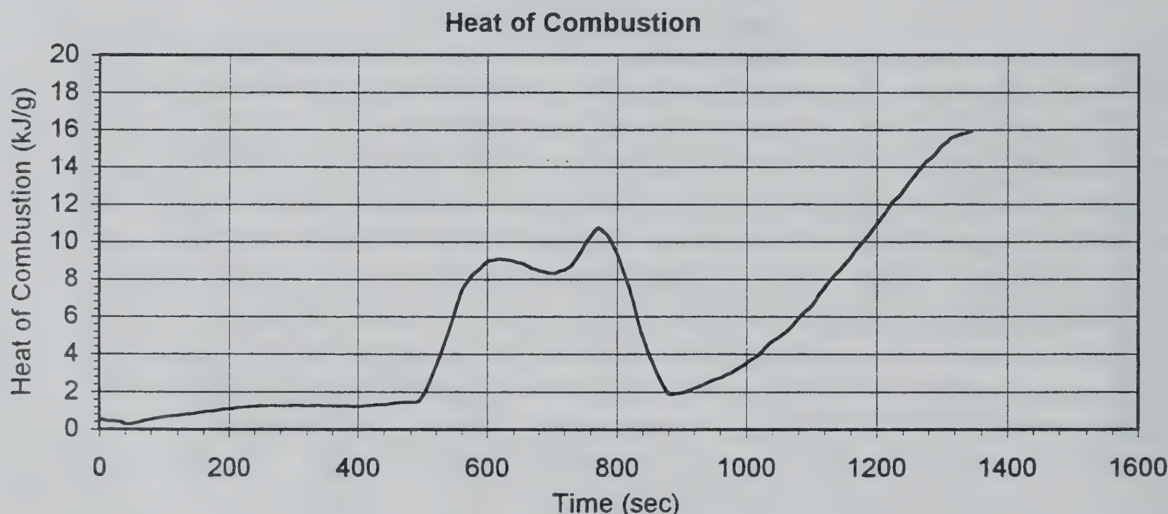
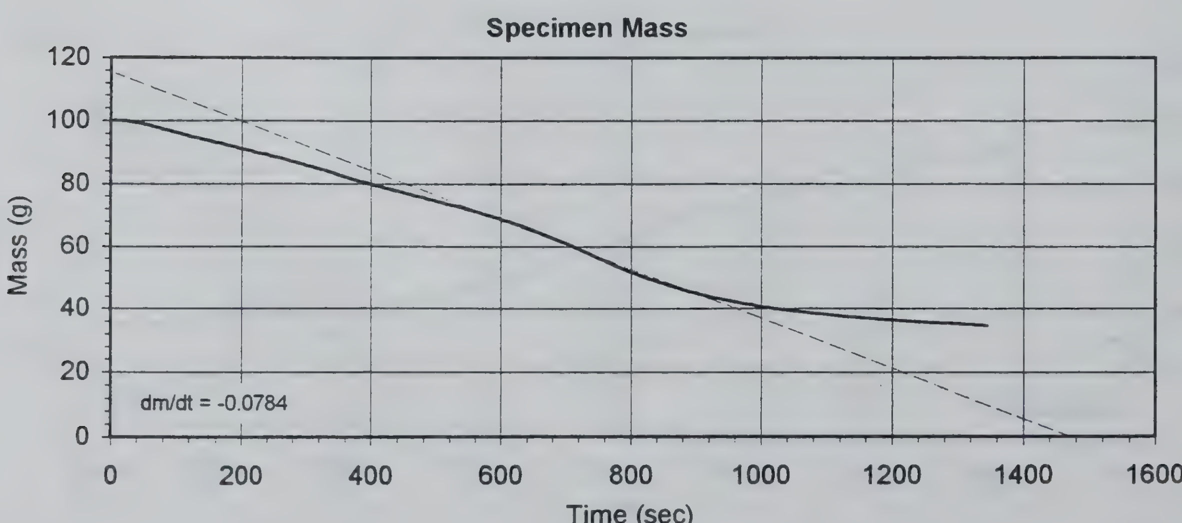
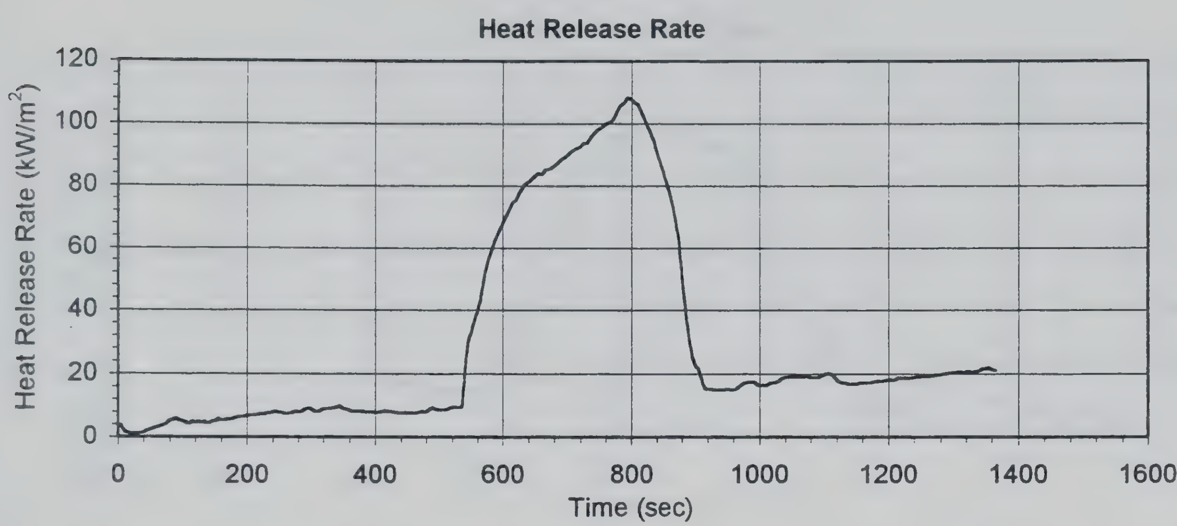
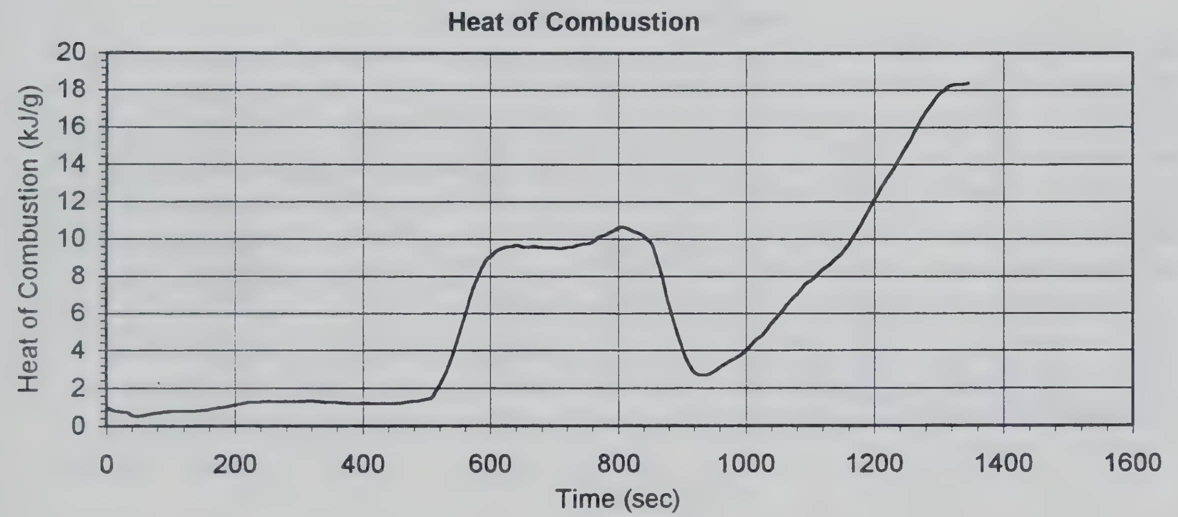


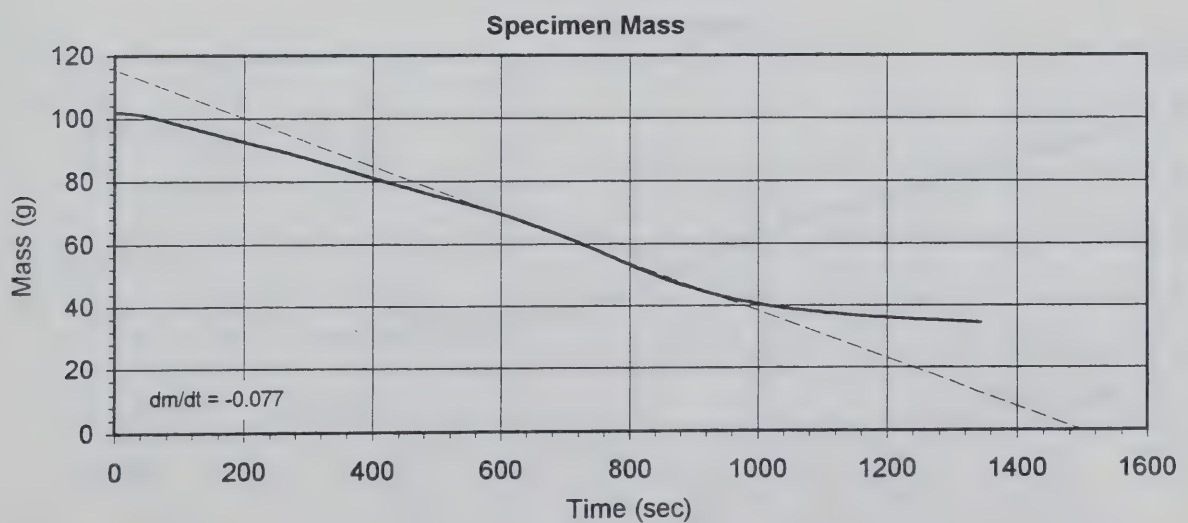




Cone Calorimeter Data R 4.01 F.R. Chipboard
40 kW/m^2, Test #3







Cone Calorimeter Data R 4.01 F.R. Chipboard

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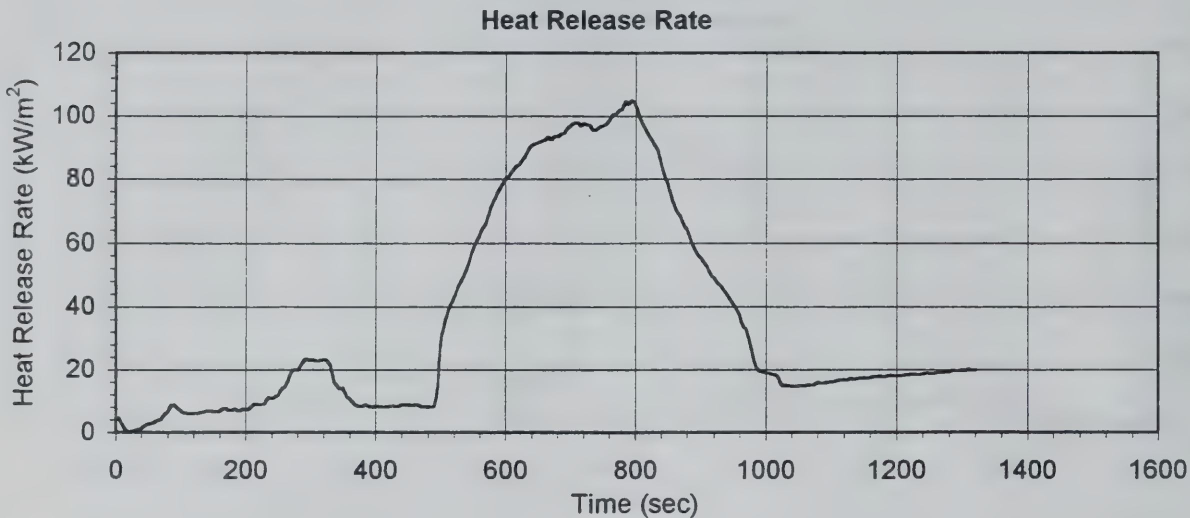

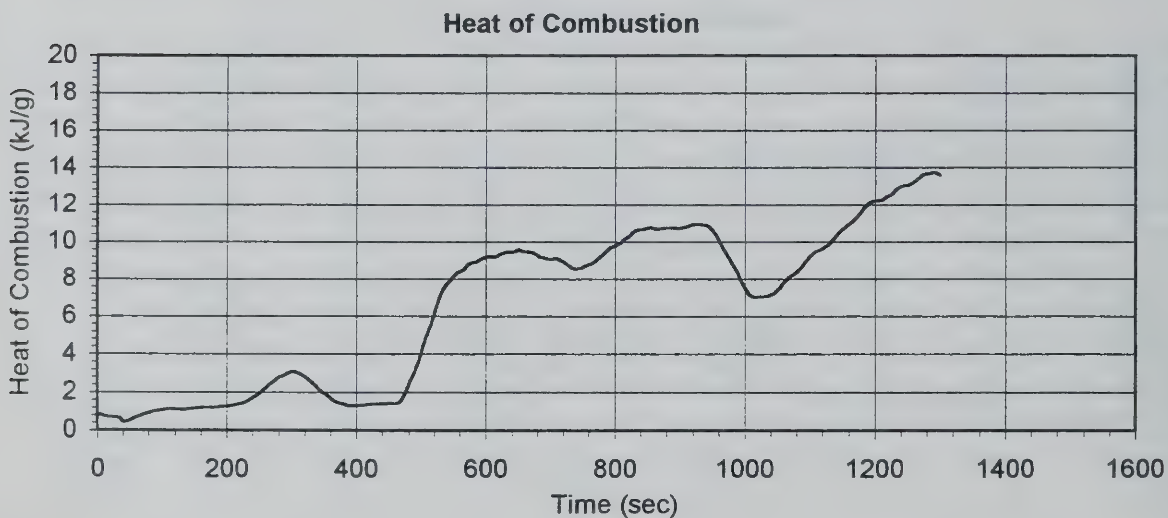

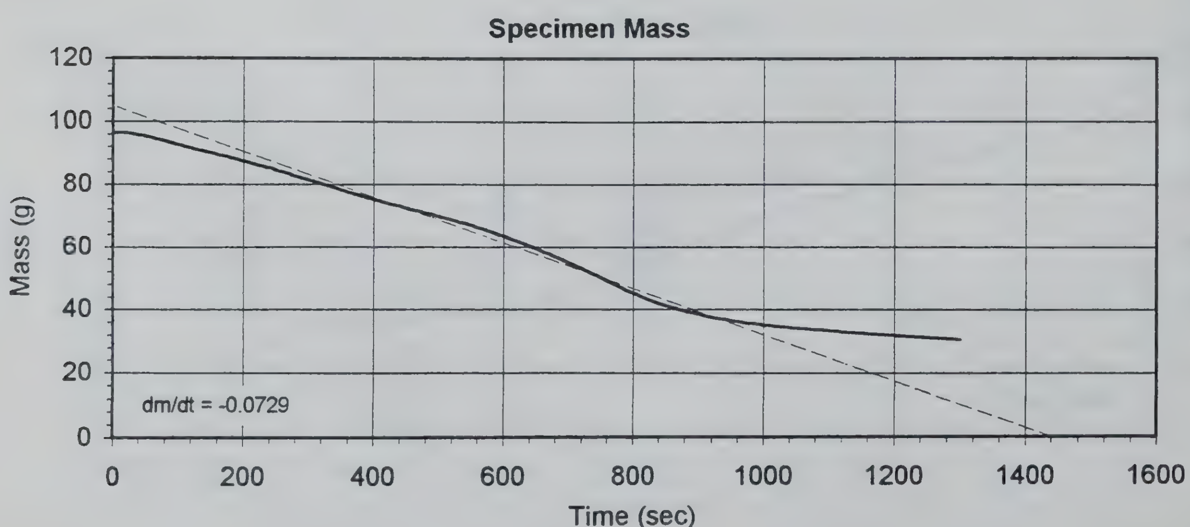

Cone Calorimeter Data R 4.01 F.R. Chipboard
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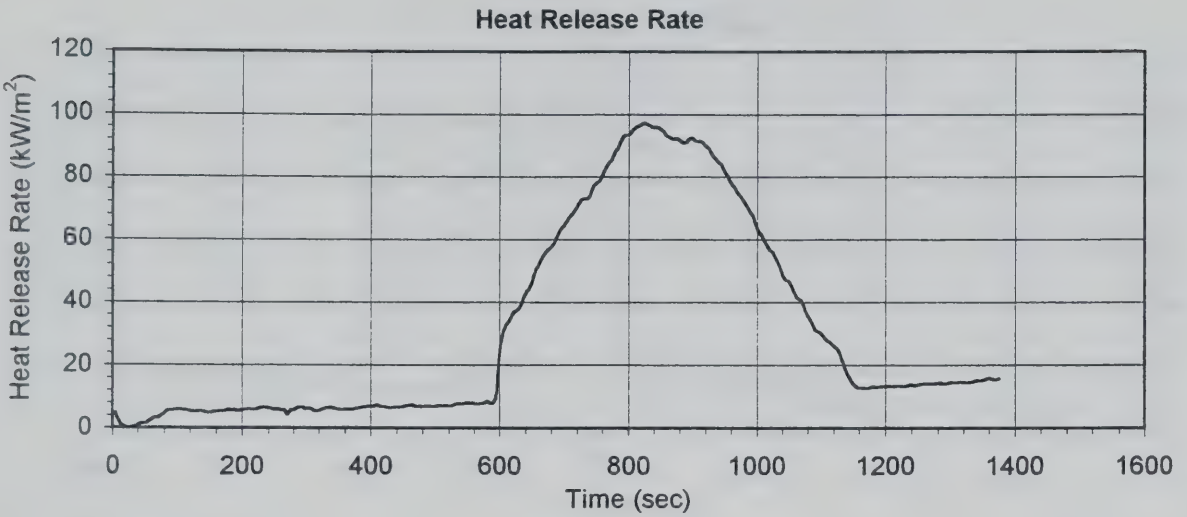
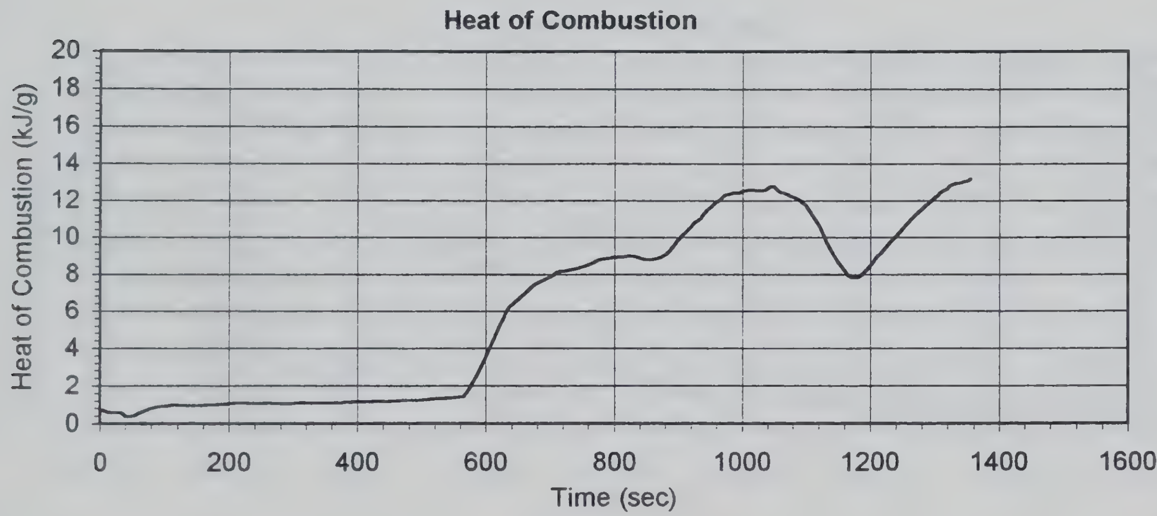
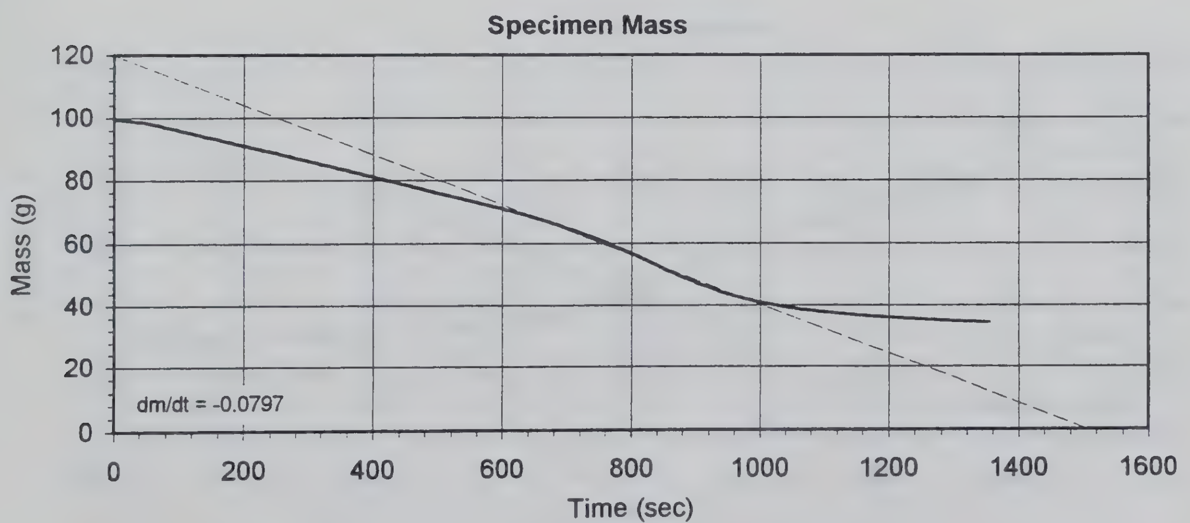
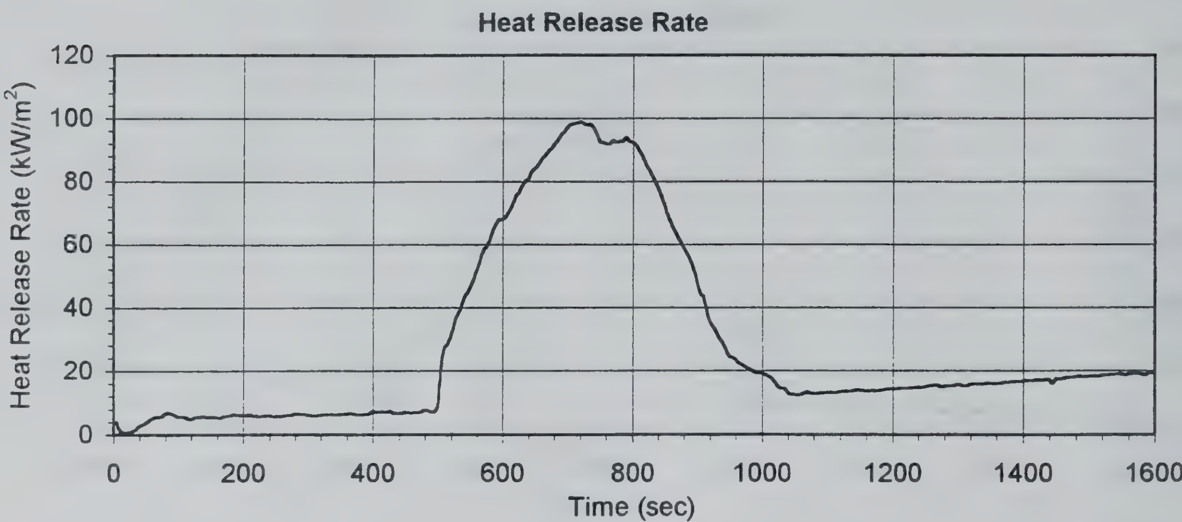
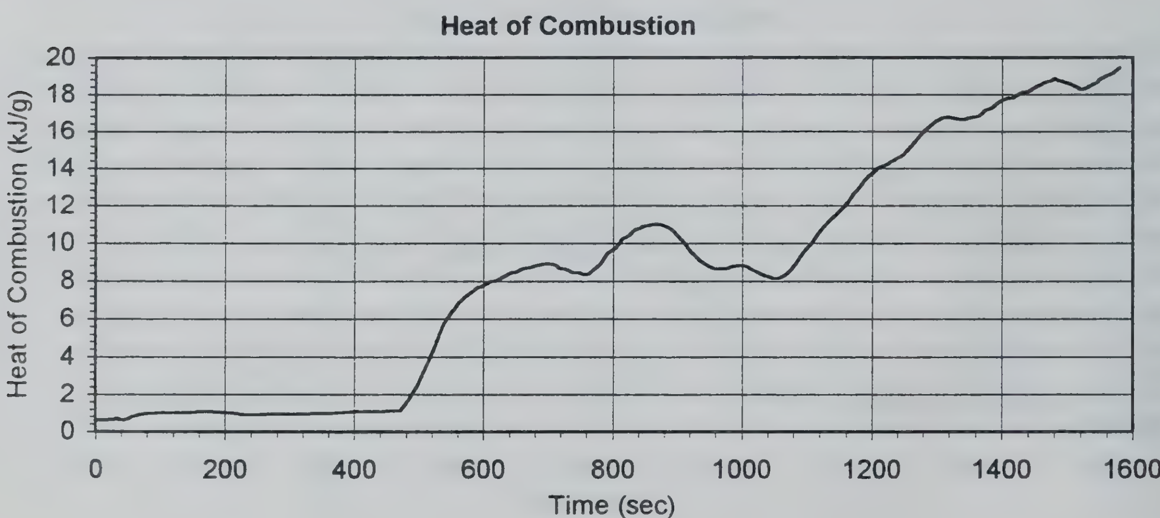


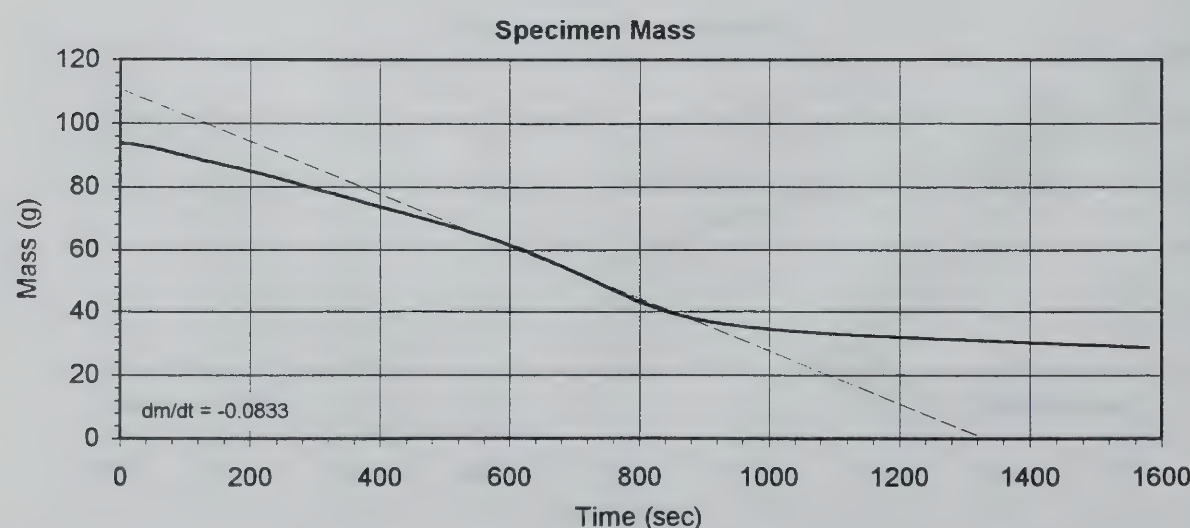




Cone Calorimeter Data R 4.01 F.R. Chipboard
50 kW/m^2, Test #1

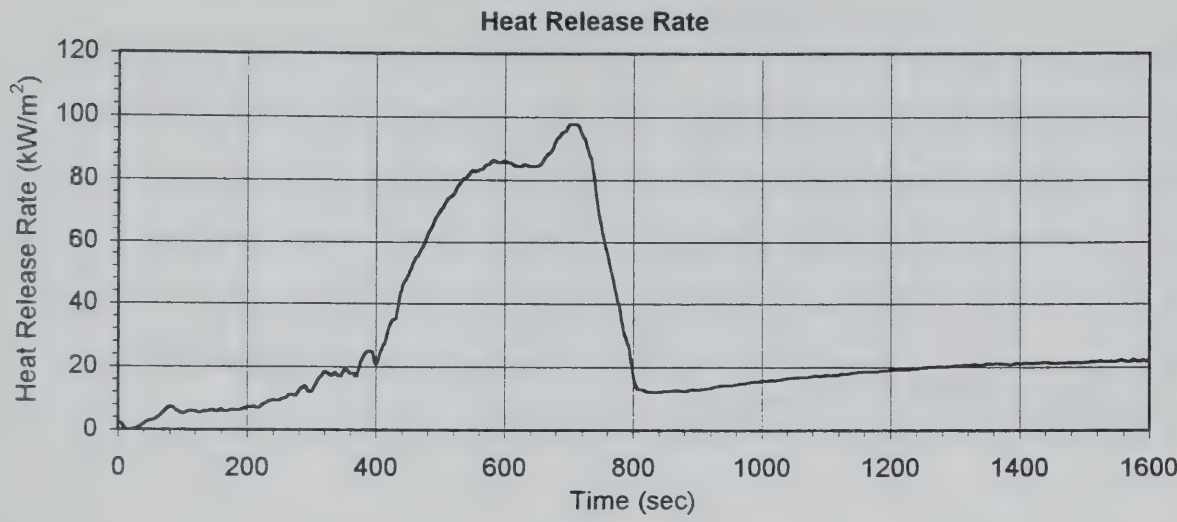


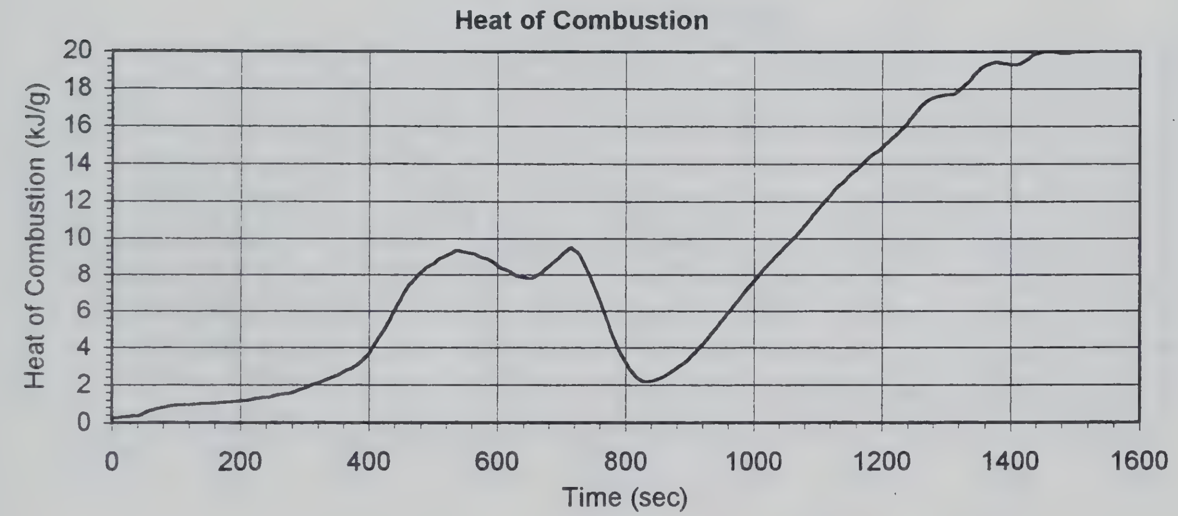


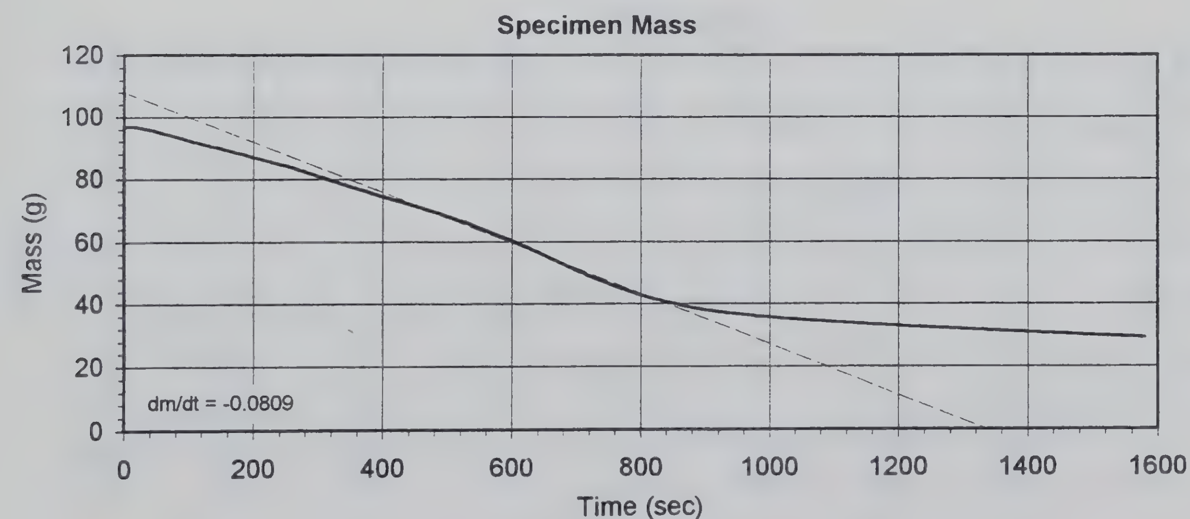


Cone Calorimeter Data R 4.01 F.R. Chipboard

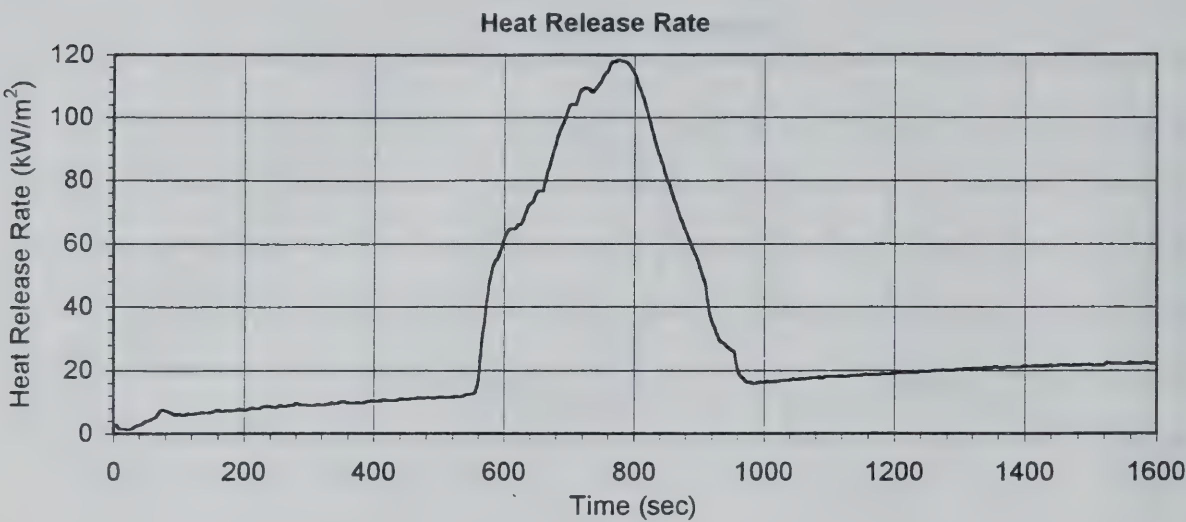
$50\ kW/m^2$, Test #2

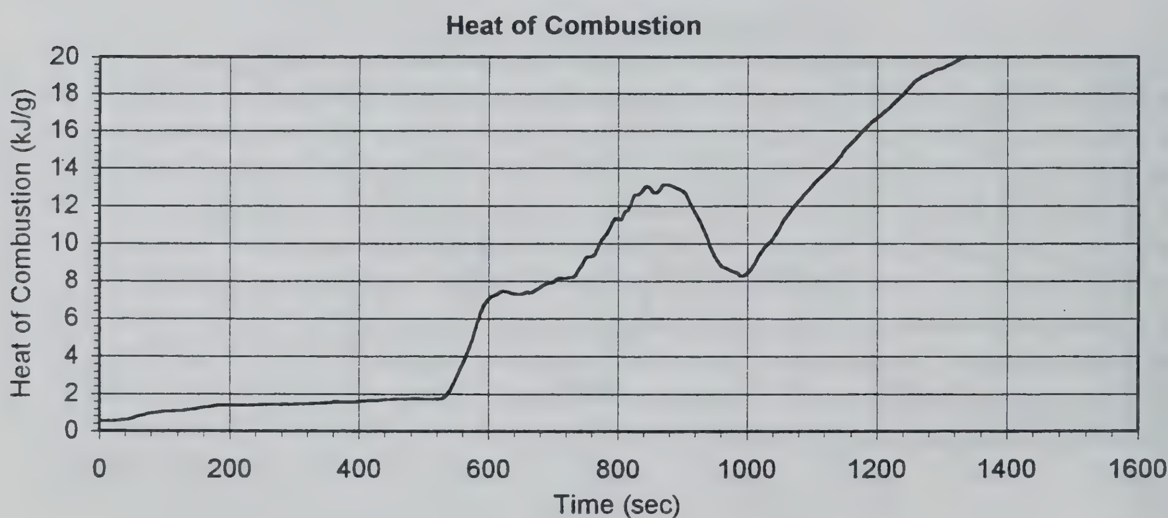


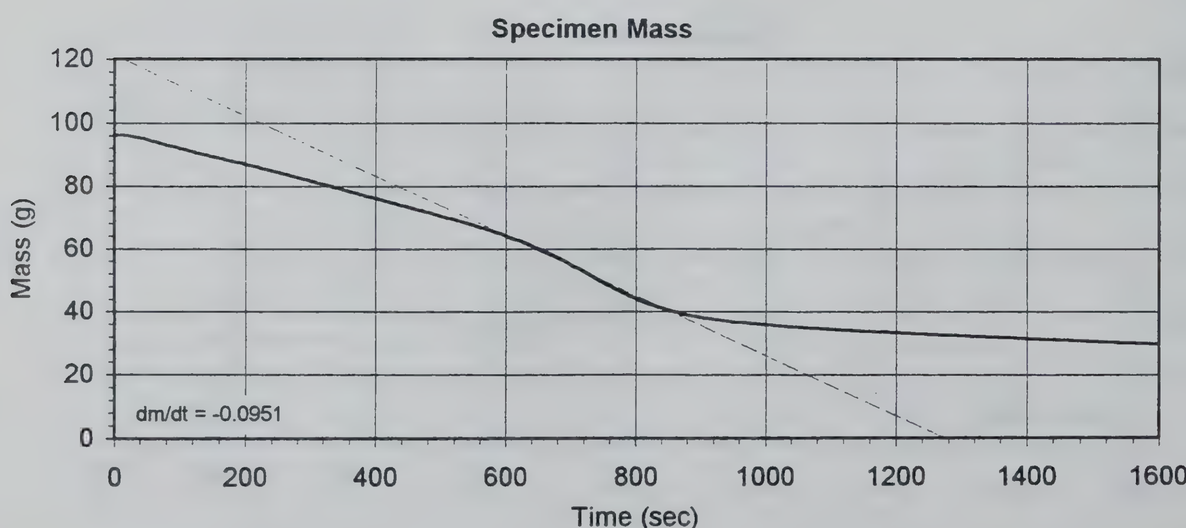




Cone Calorimeter Data R 4.01 F.R. Chipboard
50 kW/m^2, Test #3



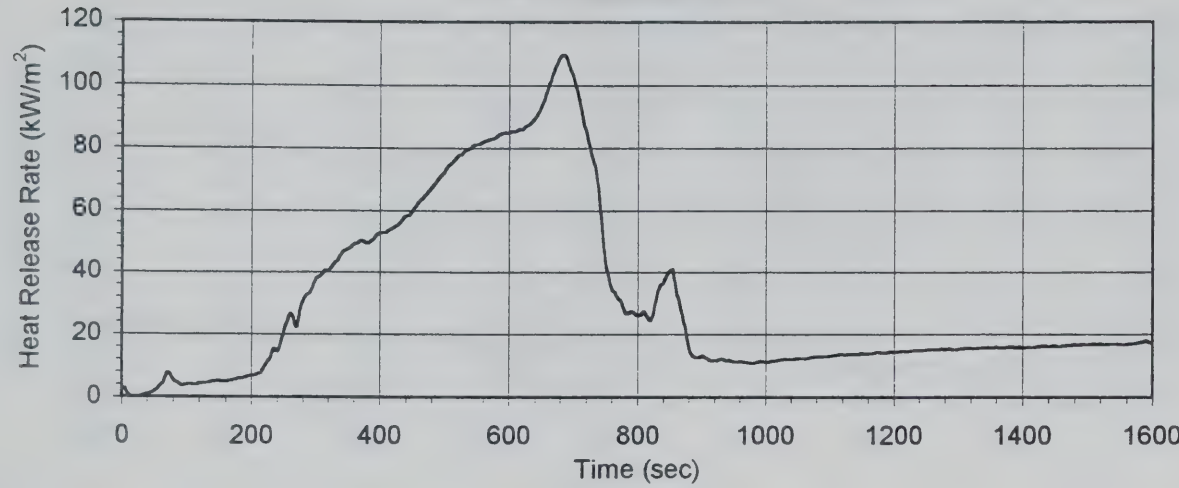




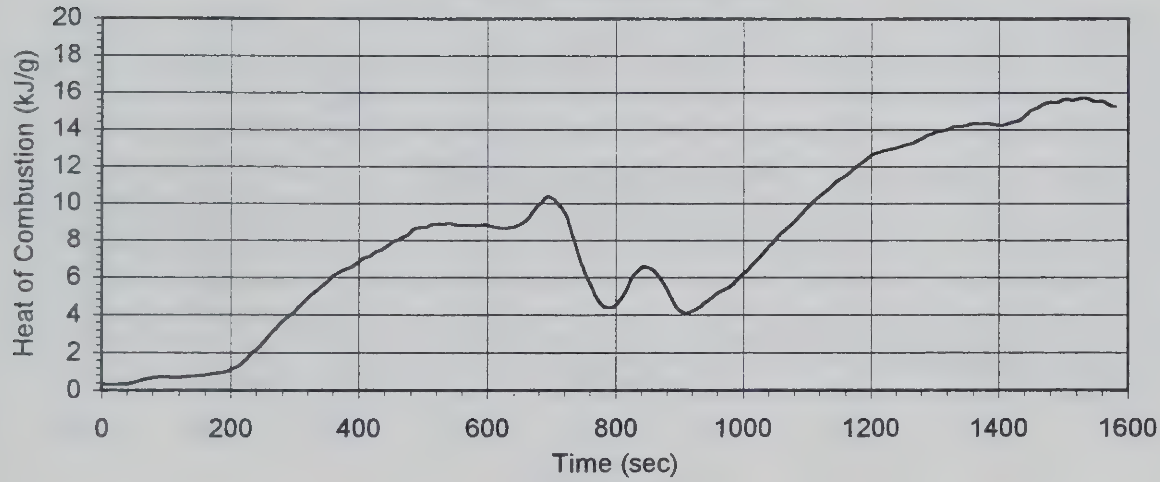
Cone Calorimeter Data R 4.01 F.R. Chipboard

50 kW/m^2, Test #4

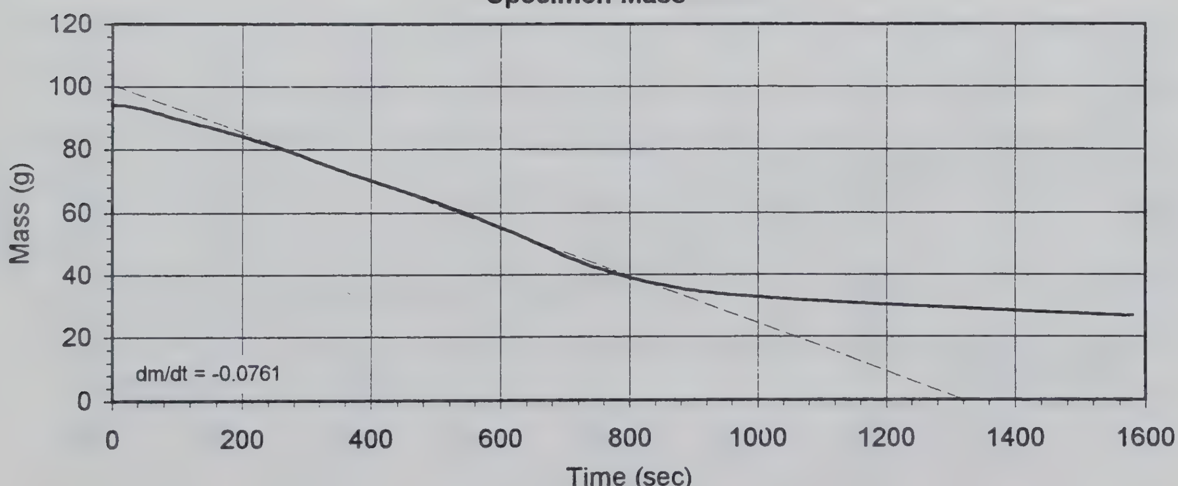
Heat Release Rate



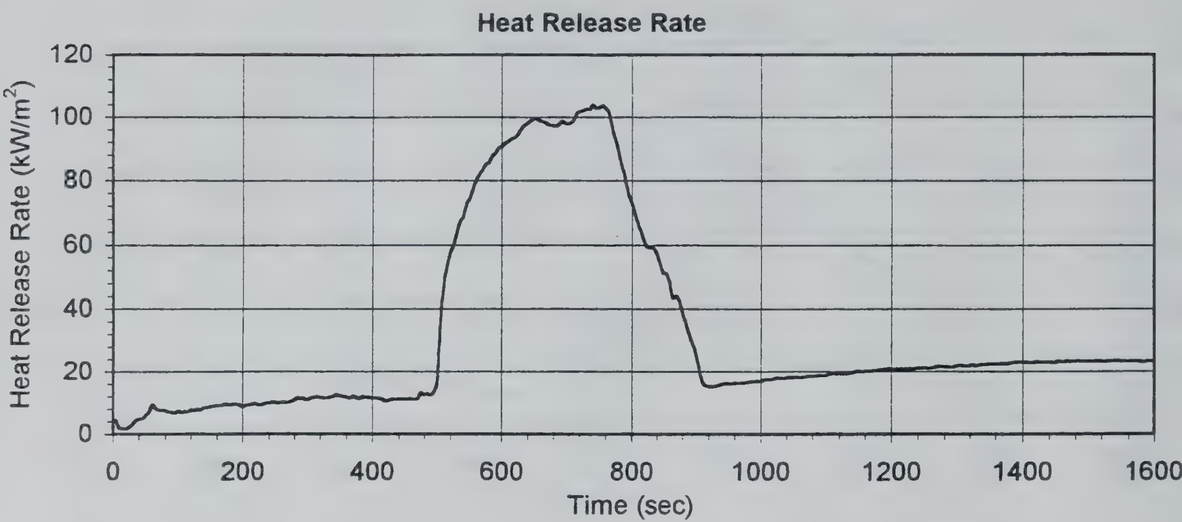
Heat of Combustion

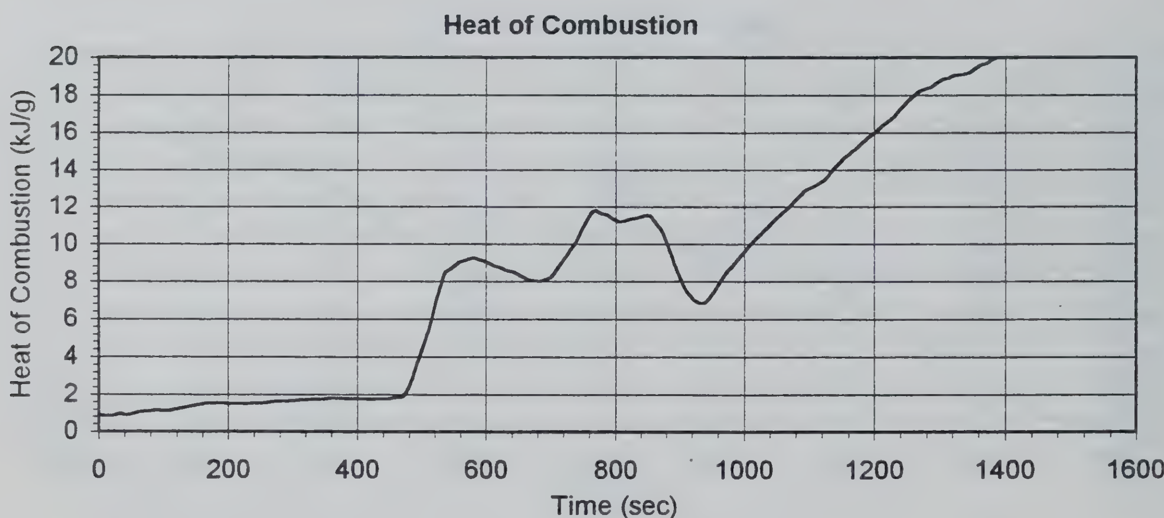


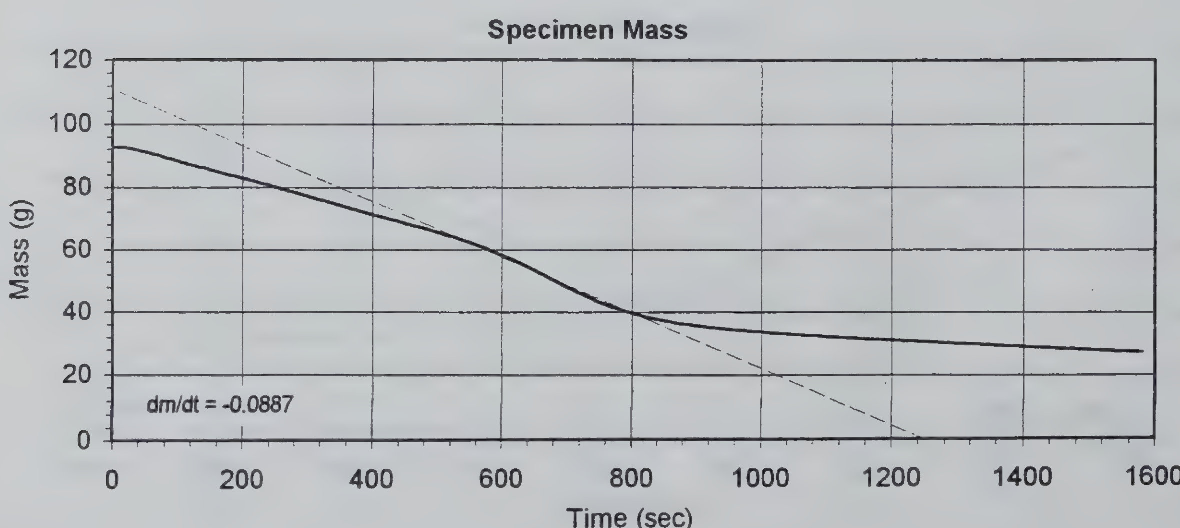
Specimen Mass



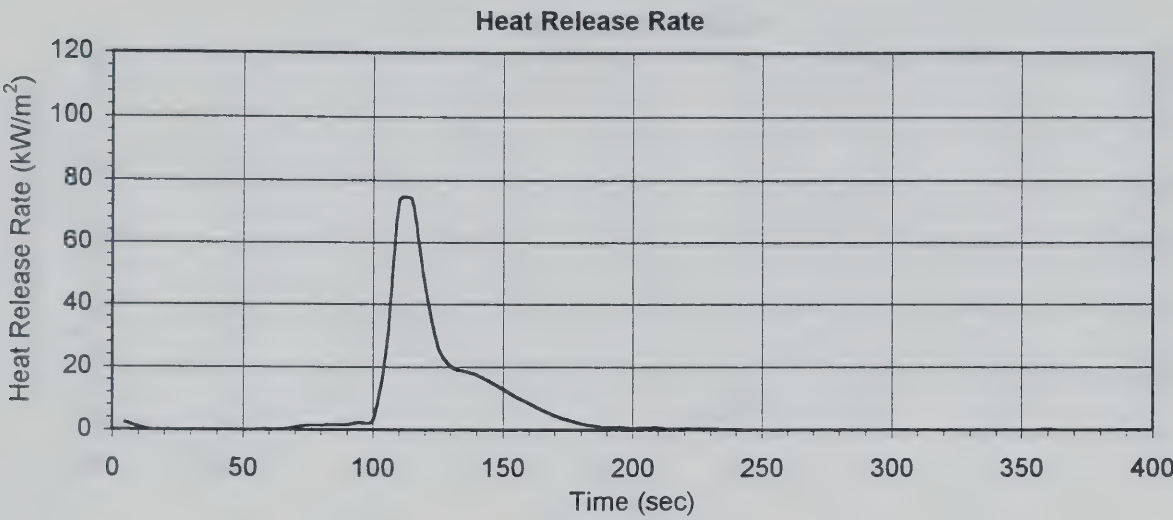
Cone Calorimeter Data R 4.01 F.R. Chipboard
50 kW/m^2, Test #5

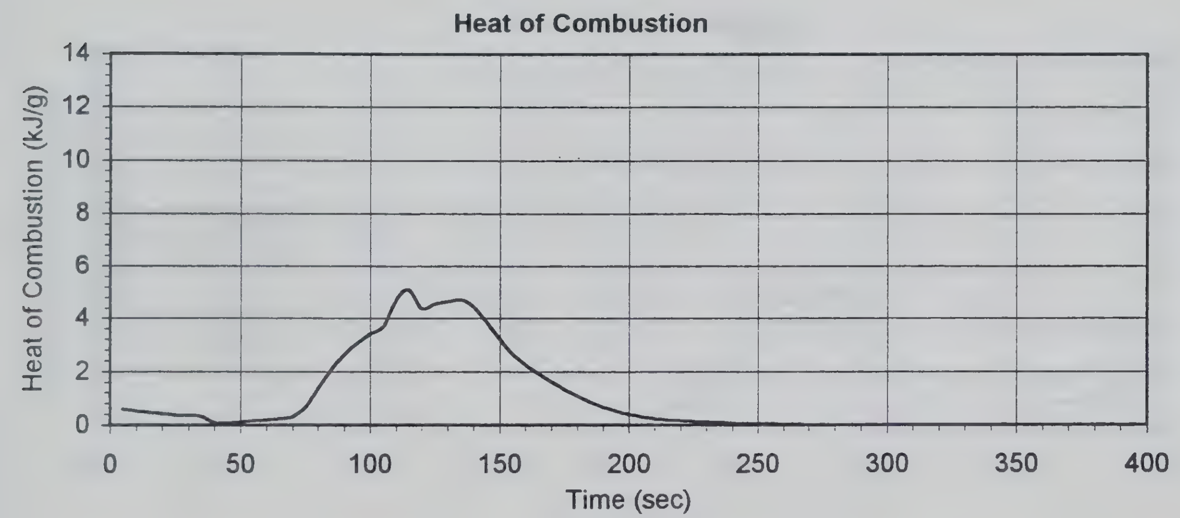


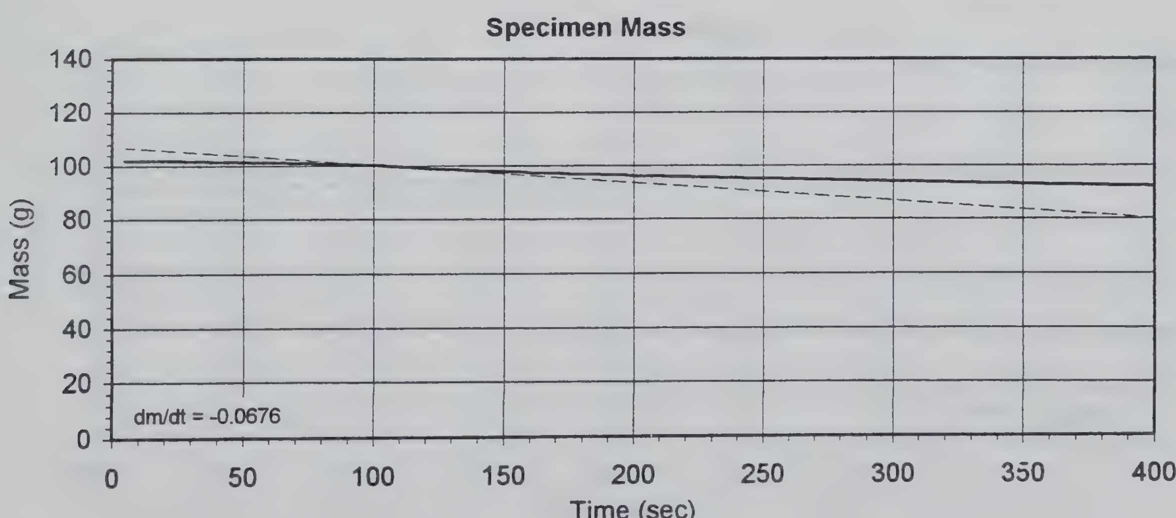




Cone Calorimeter Data R 4.02 Paper Faced Gypsum Board
35 kW/m^2, Test #1







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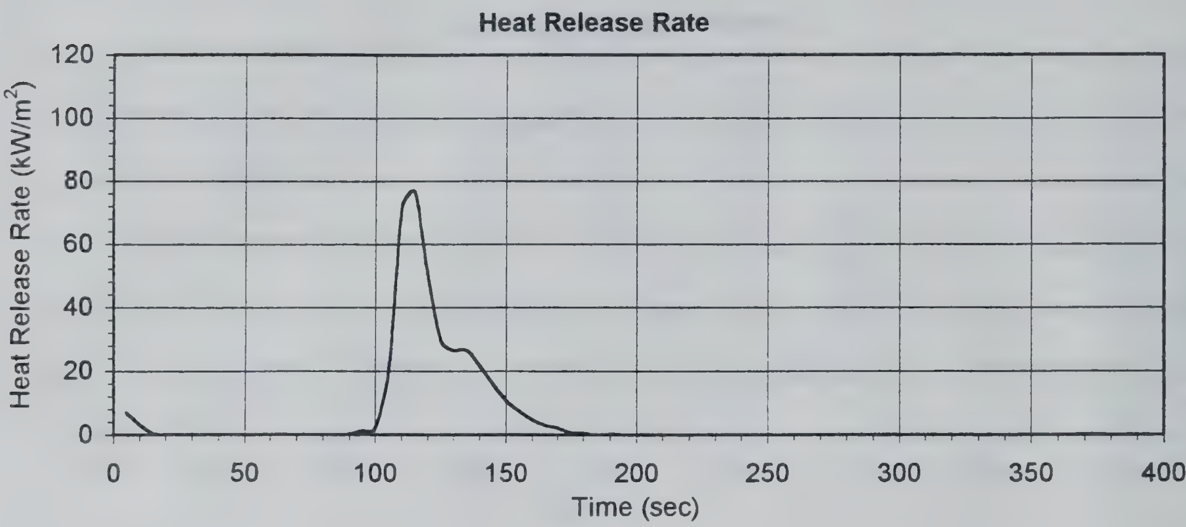

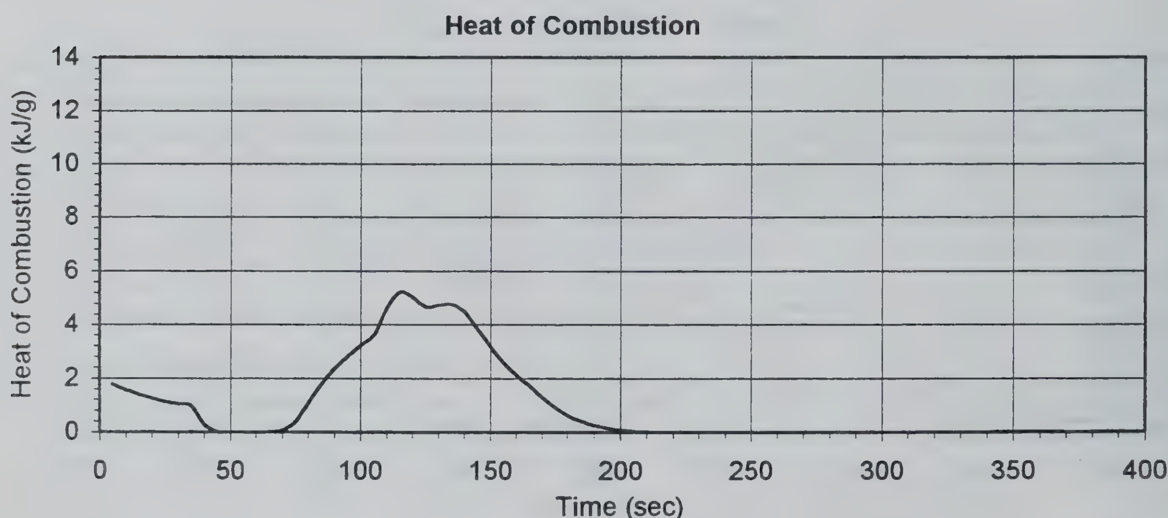

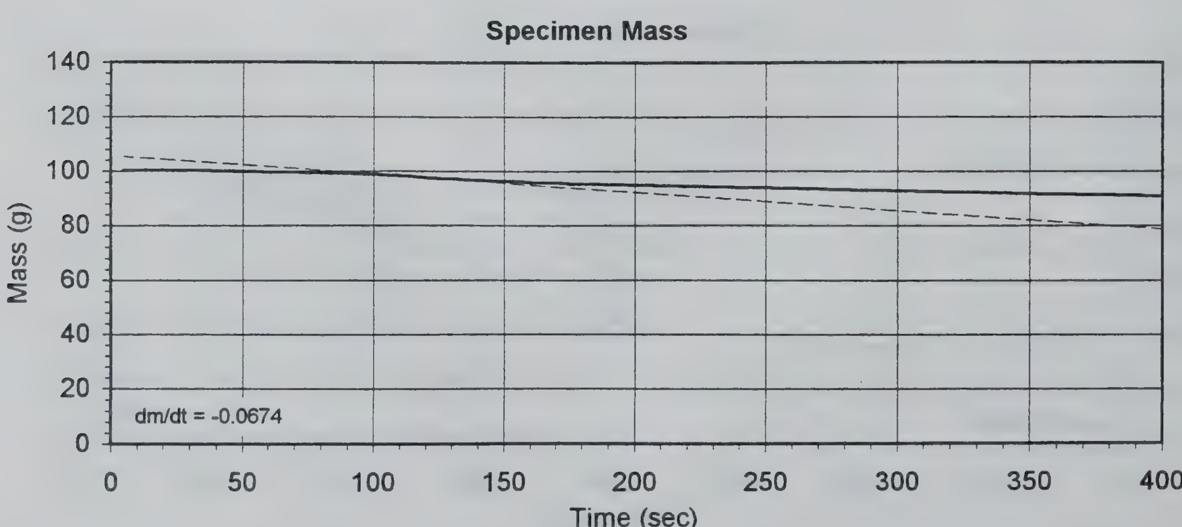

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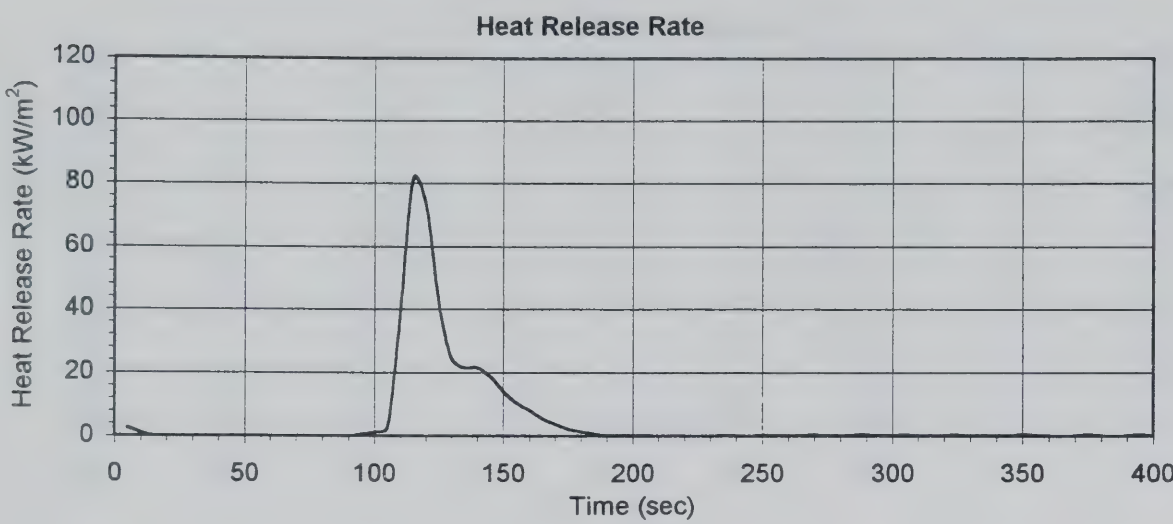

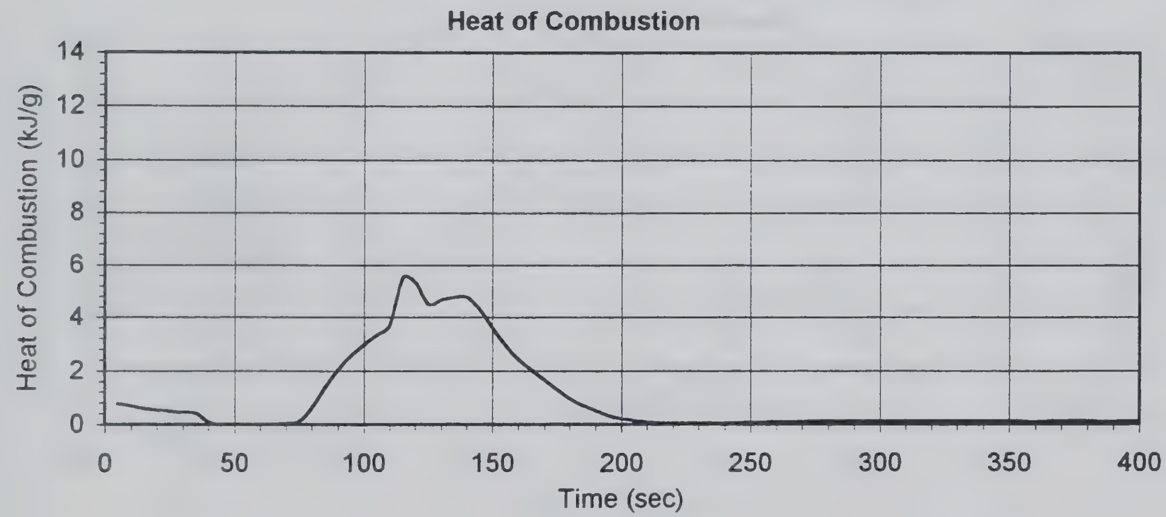

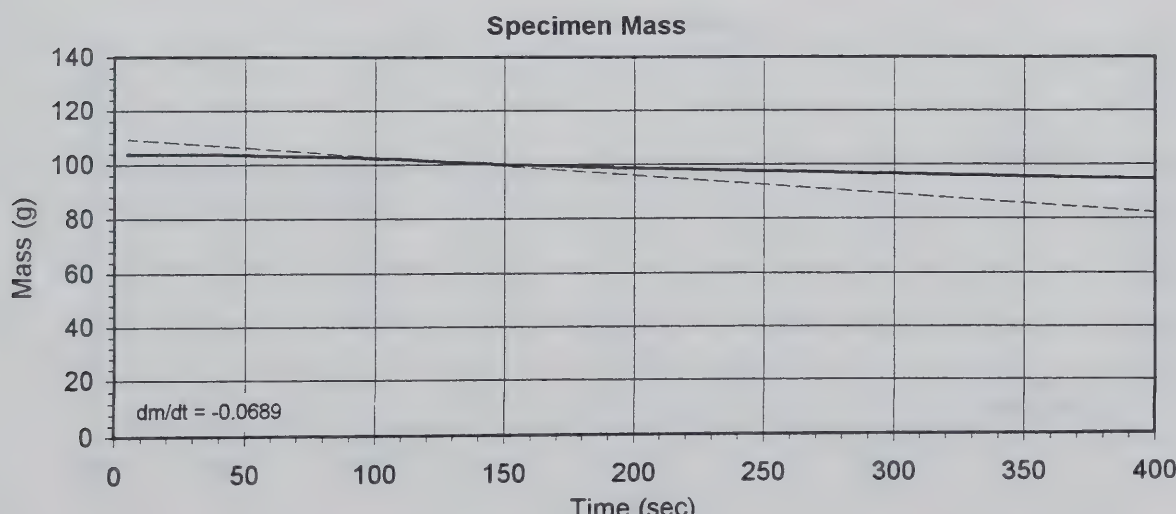

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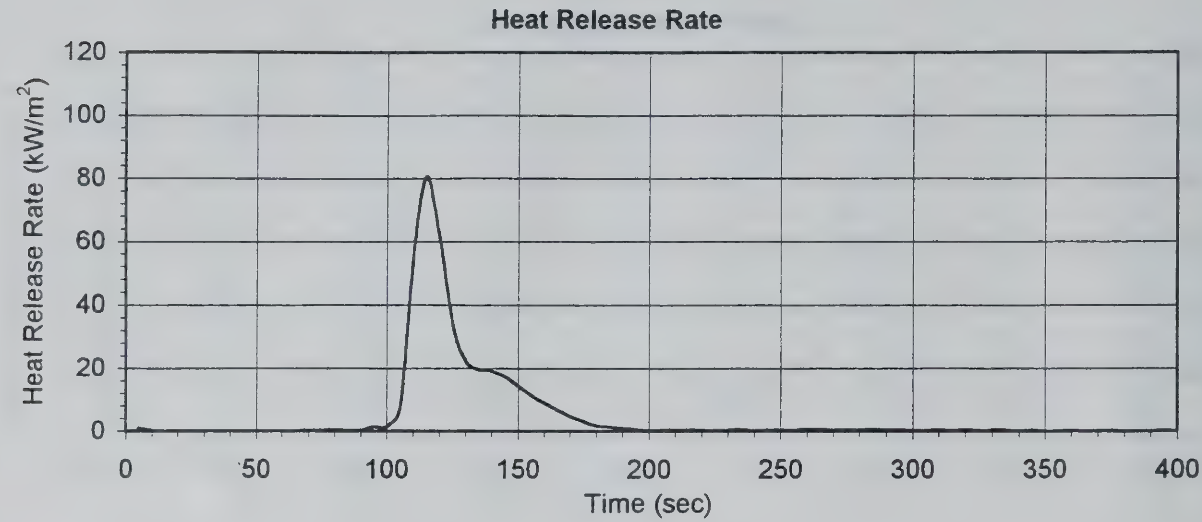

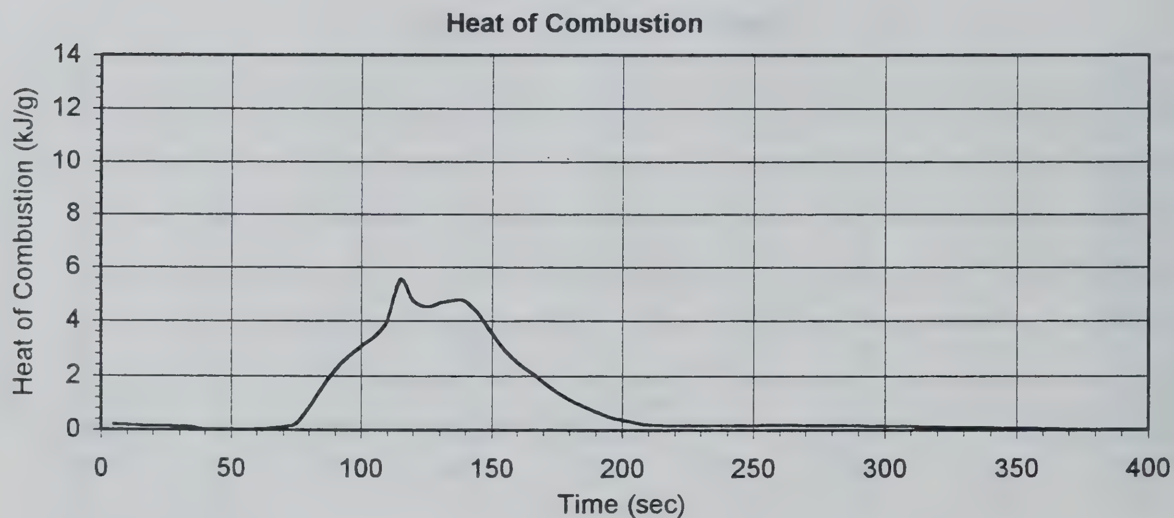

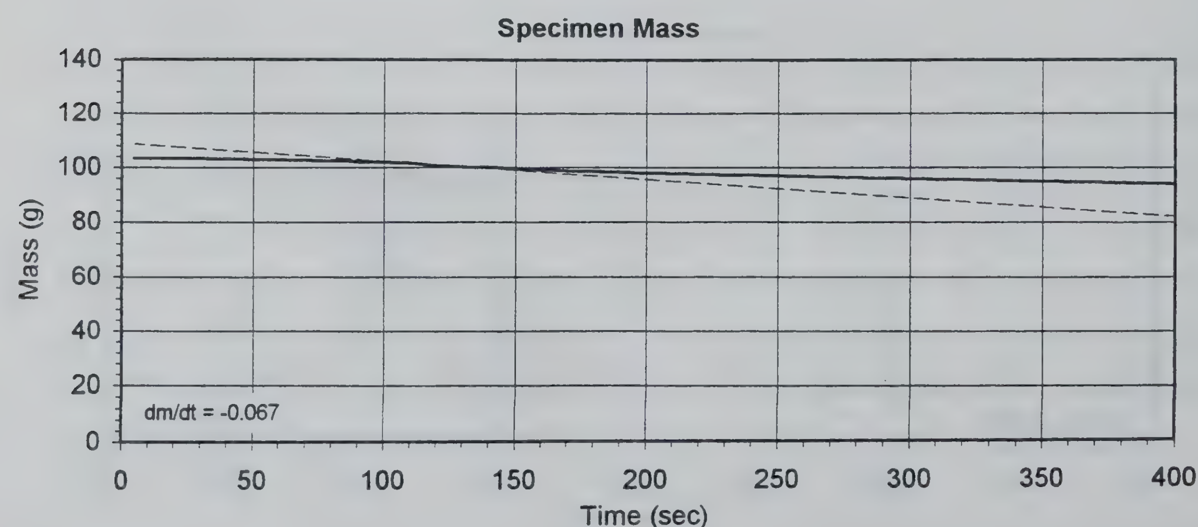

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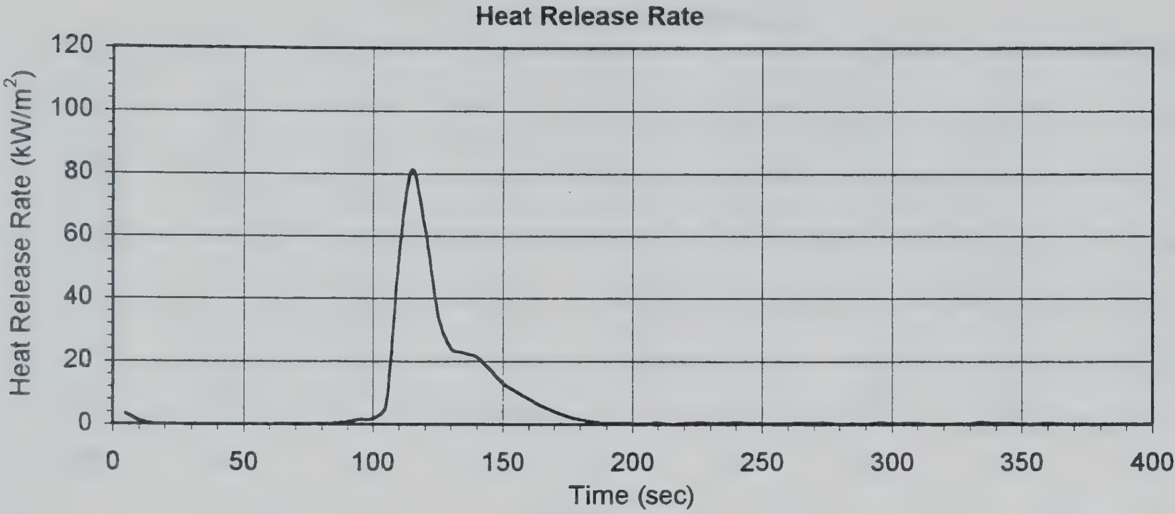

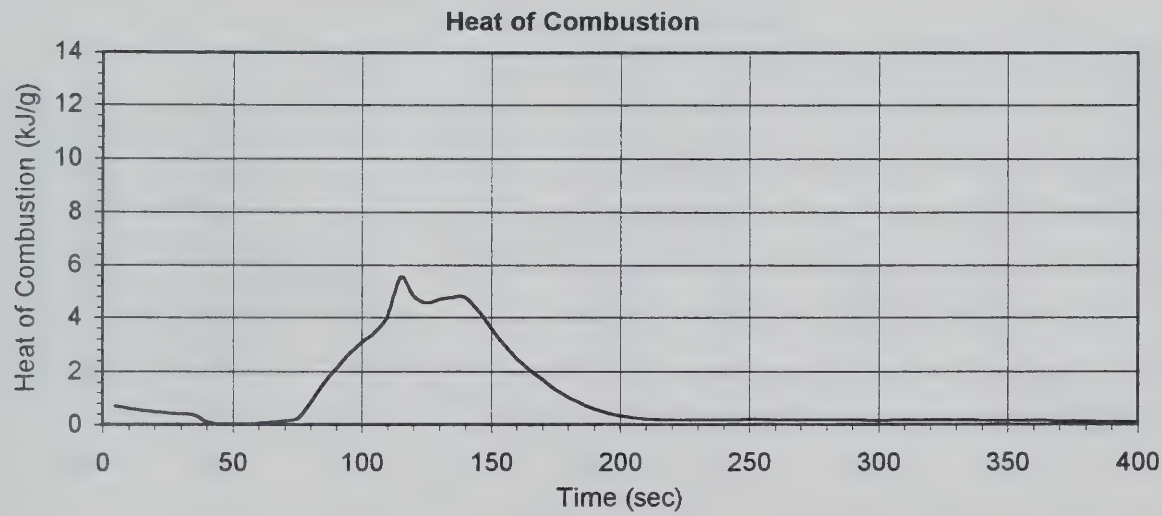

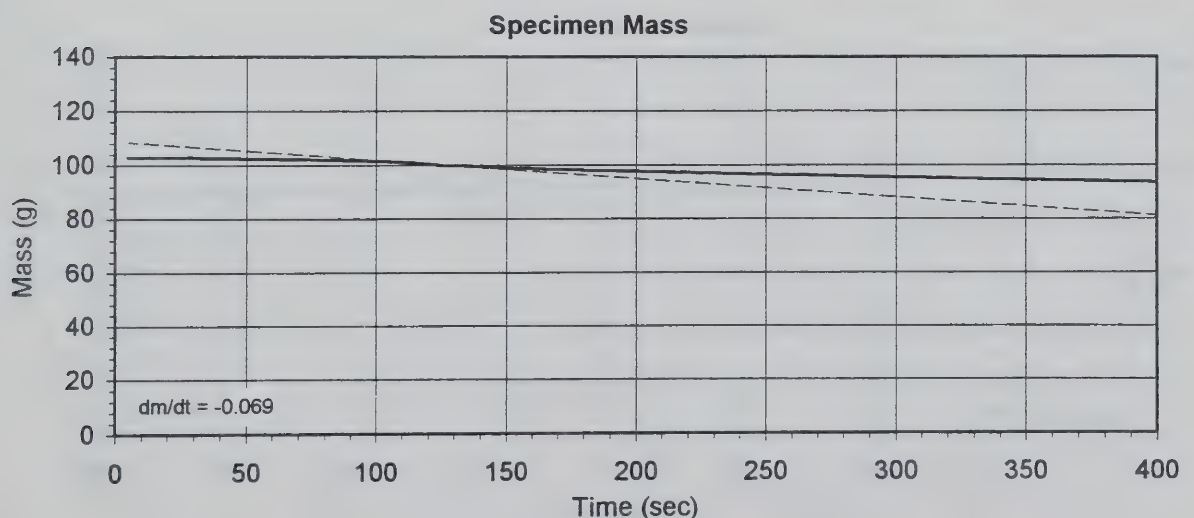

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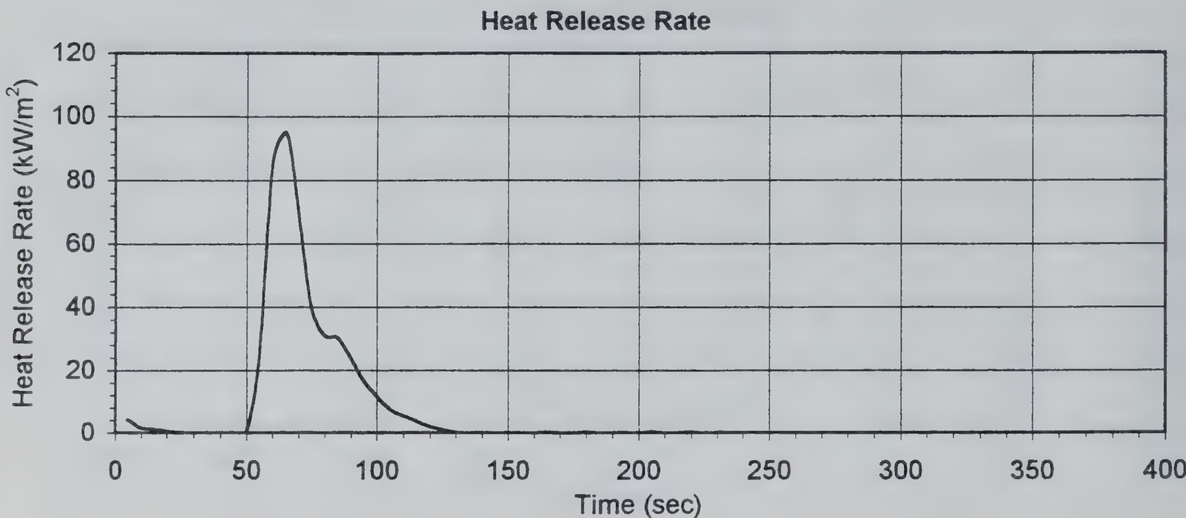

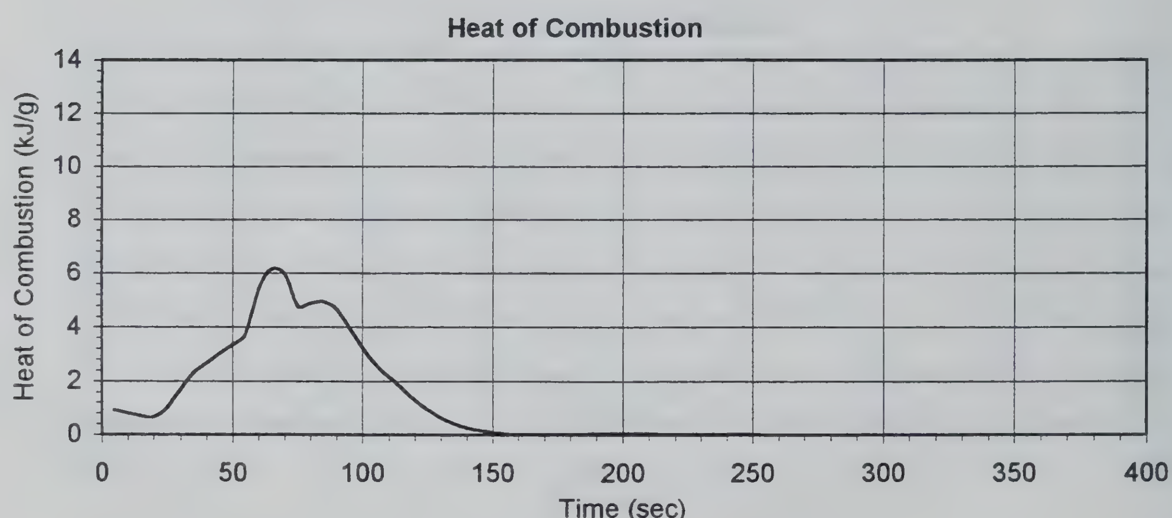

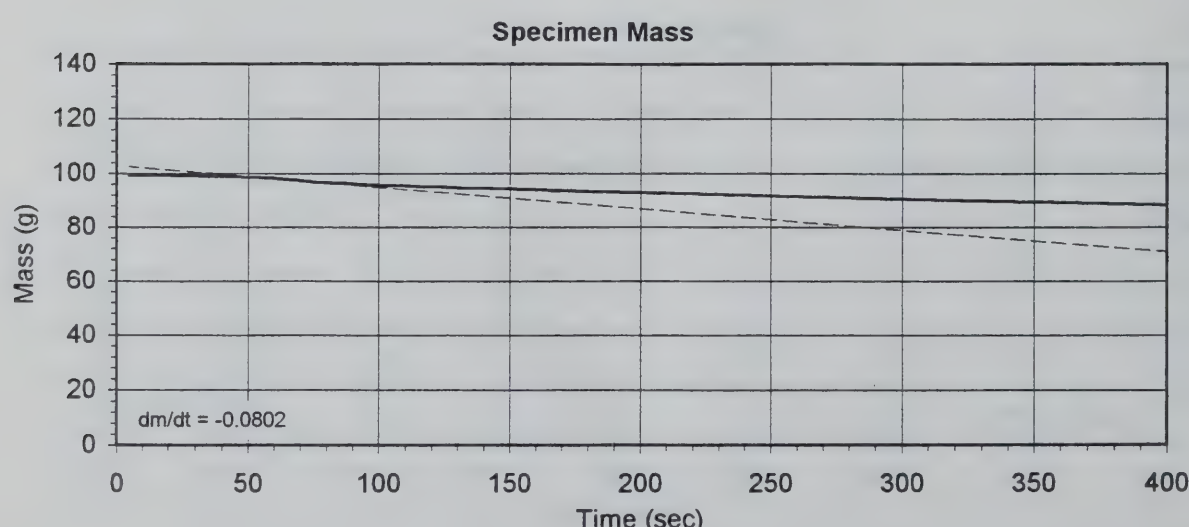

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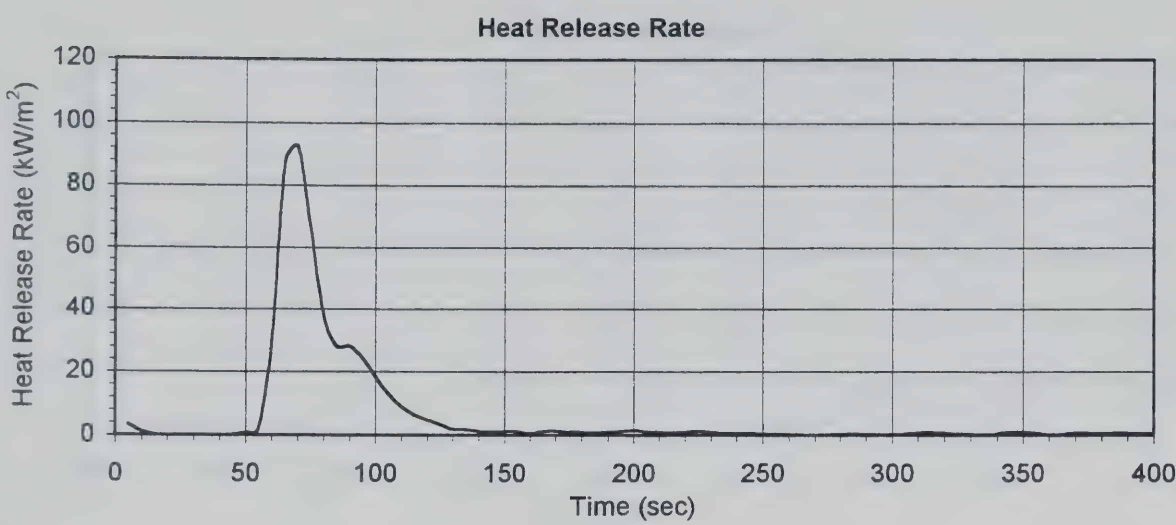

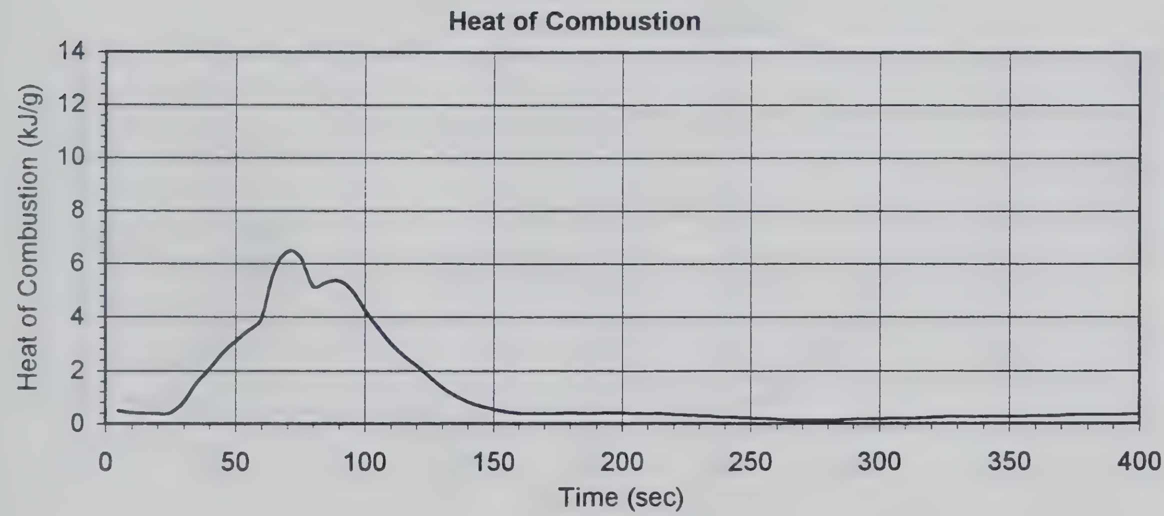

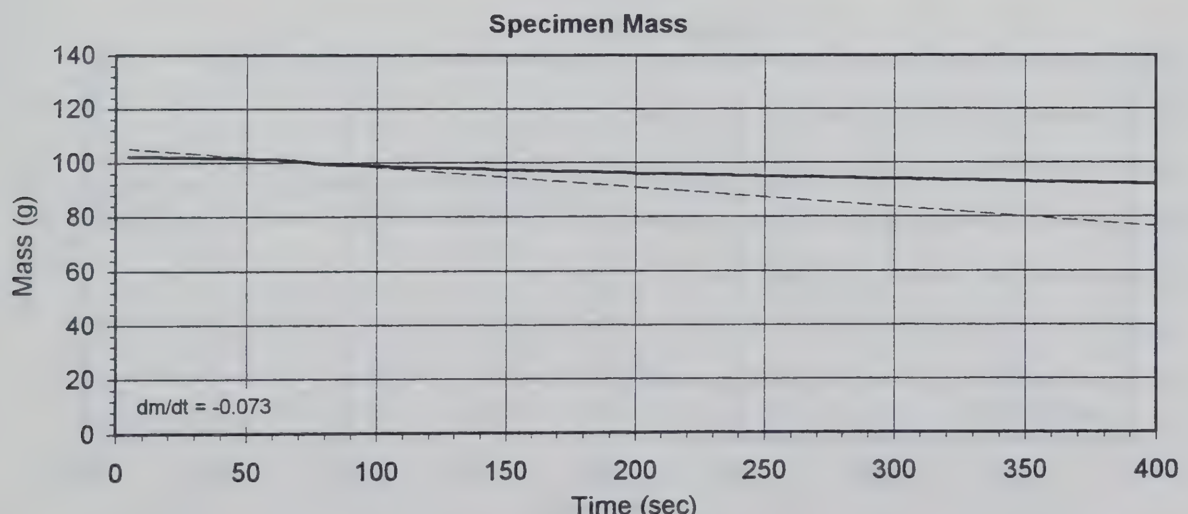

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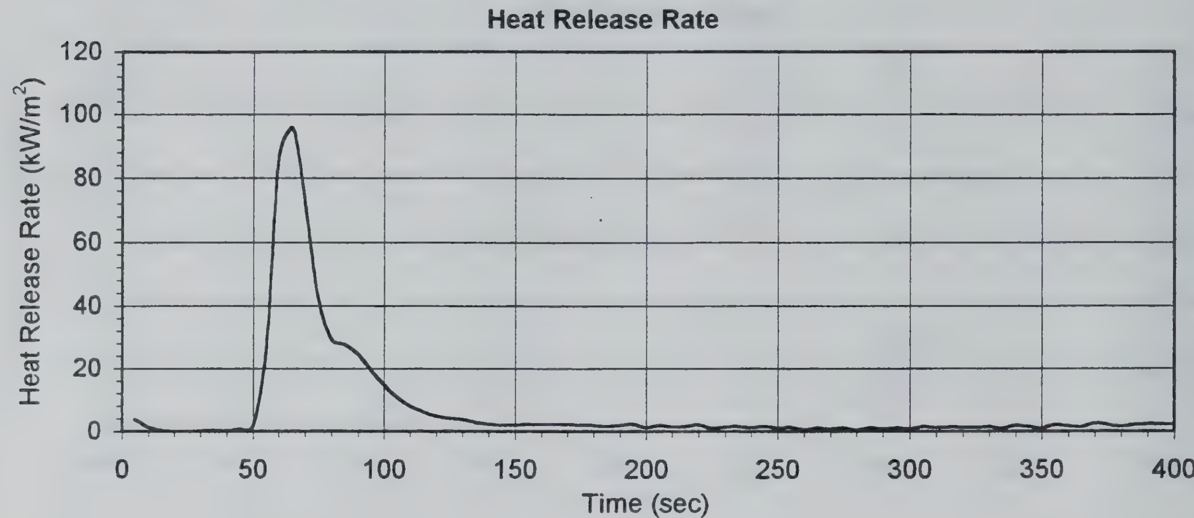

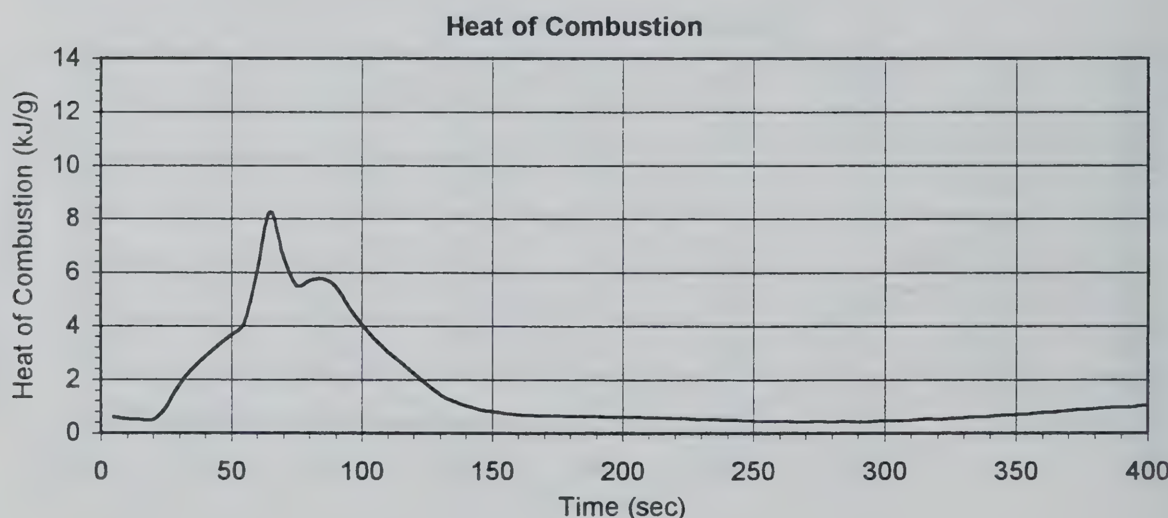

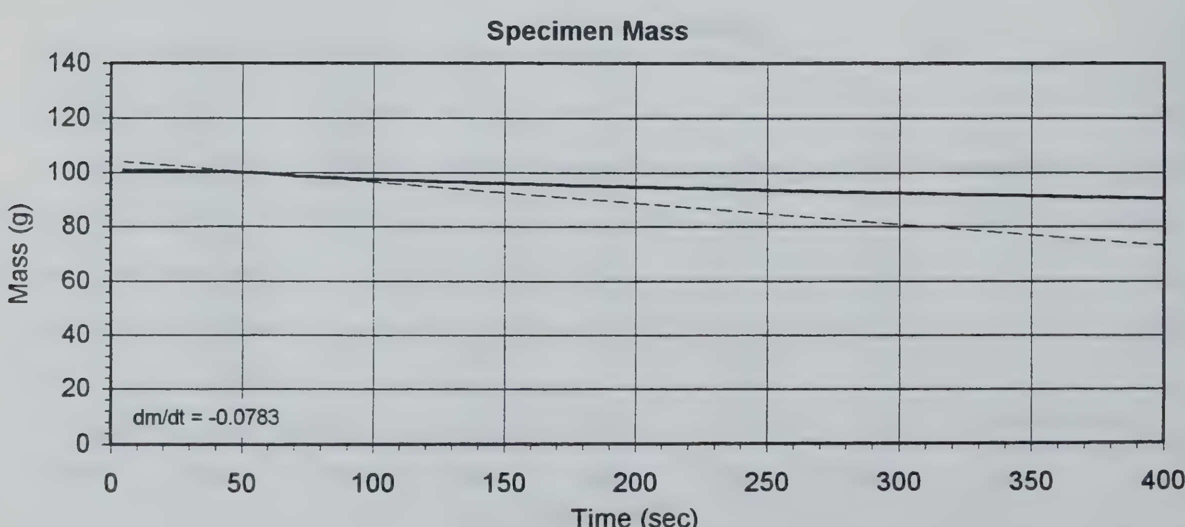

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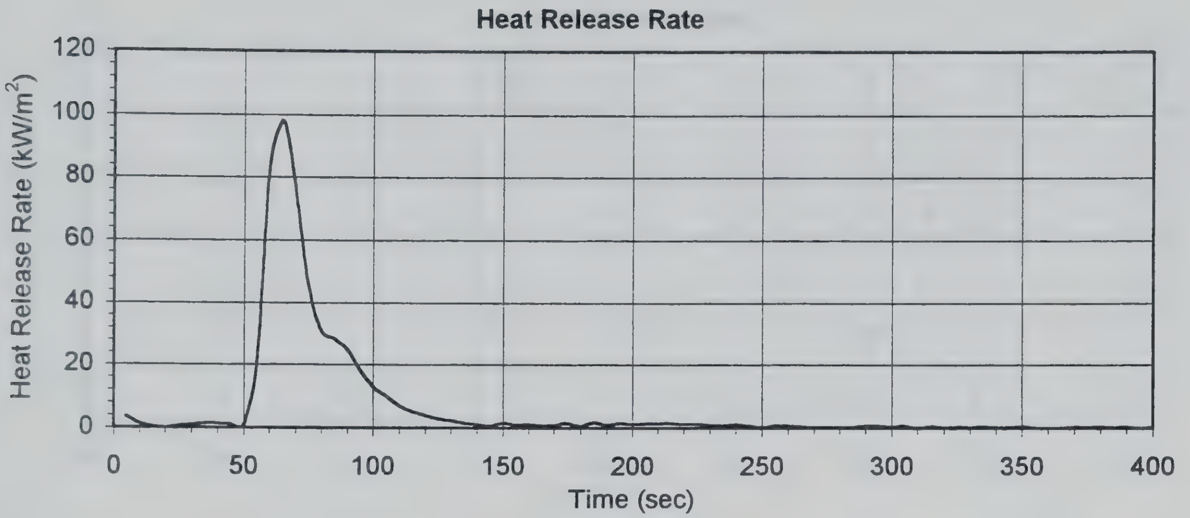
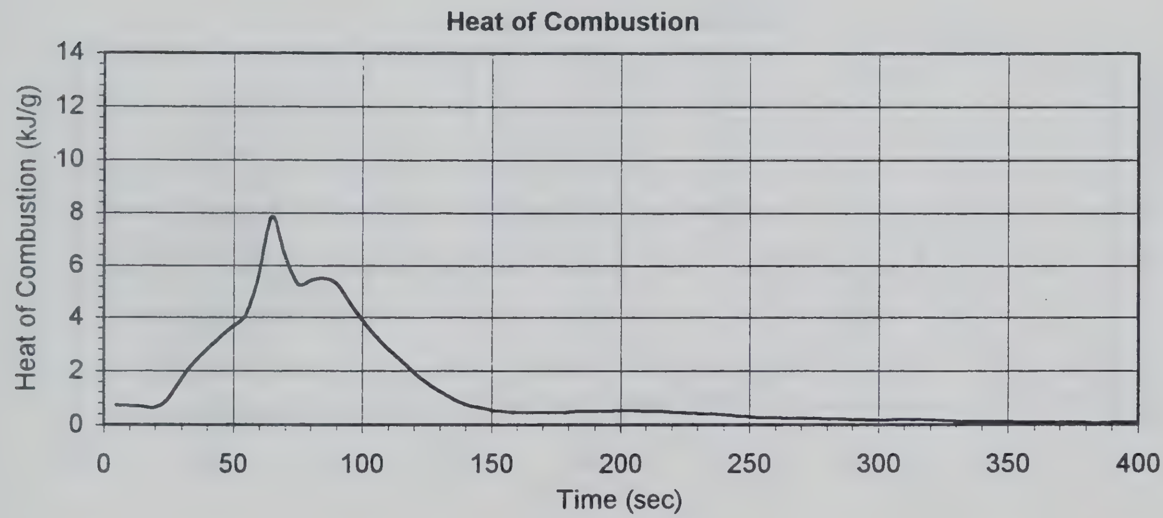
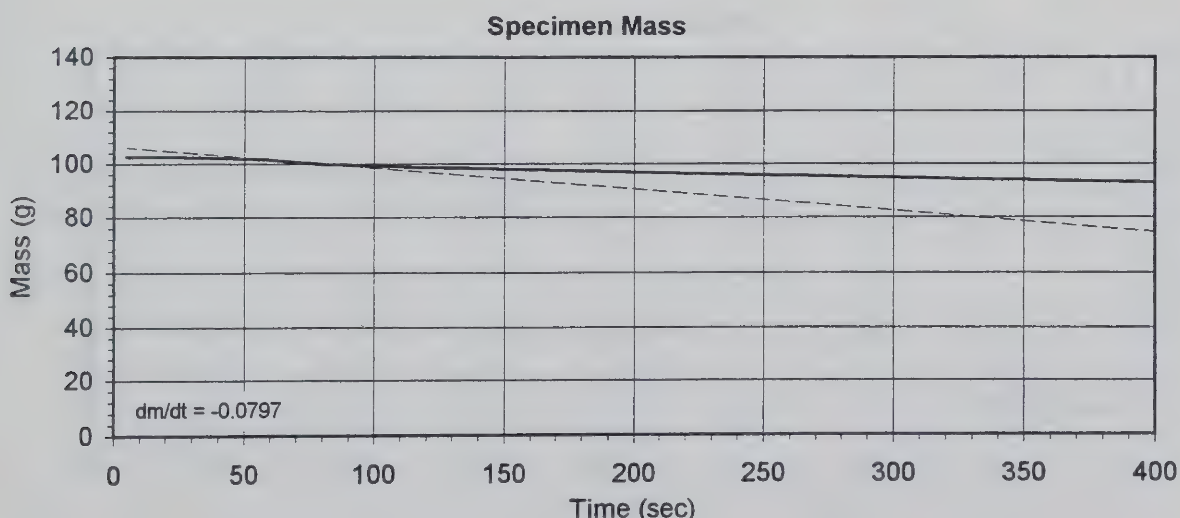
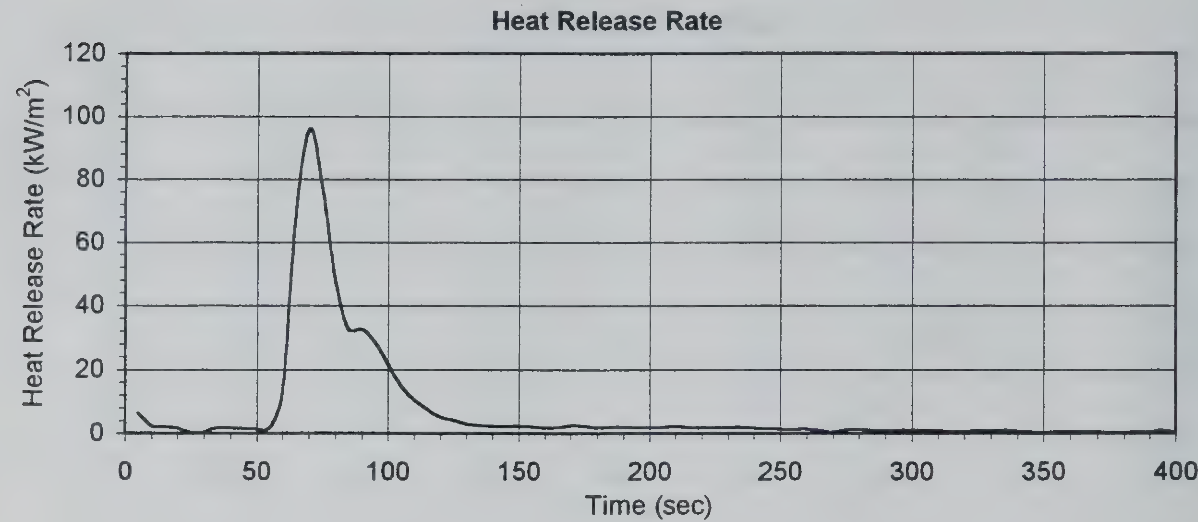
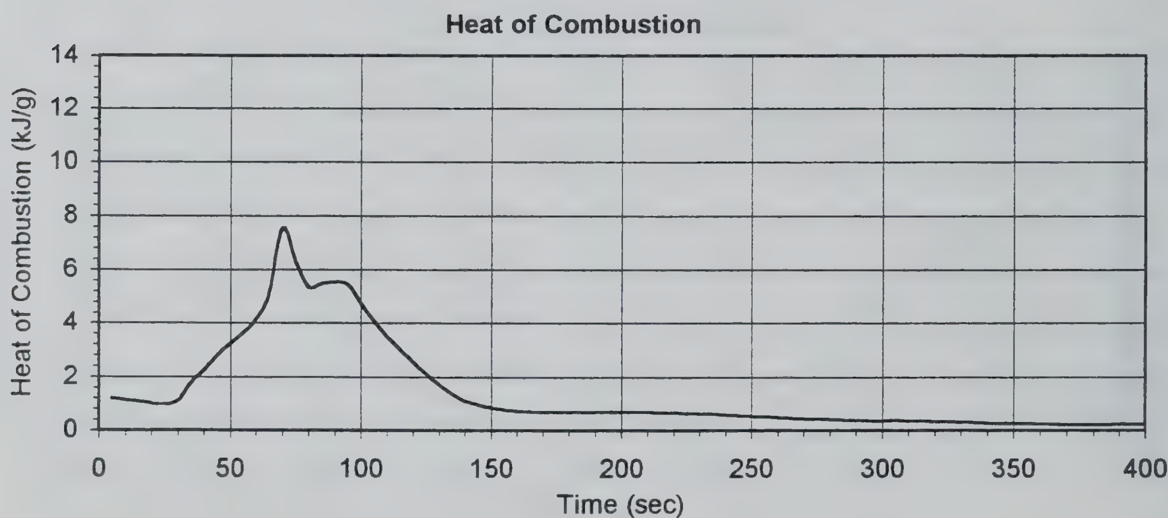


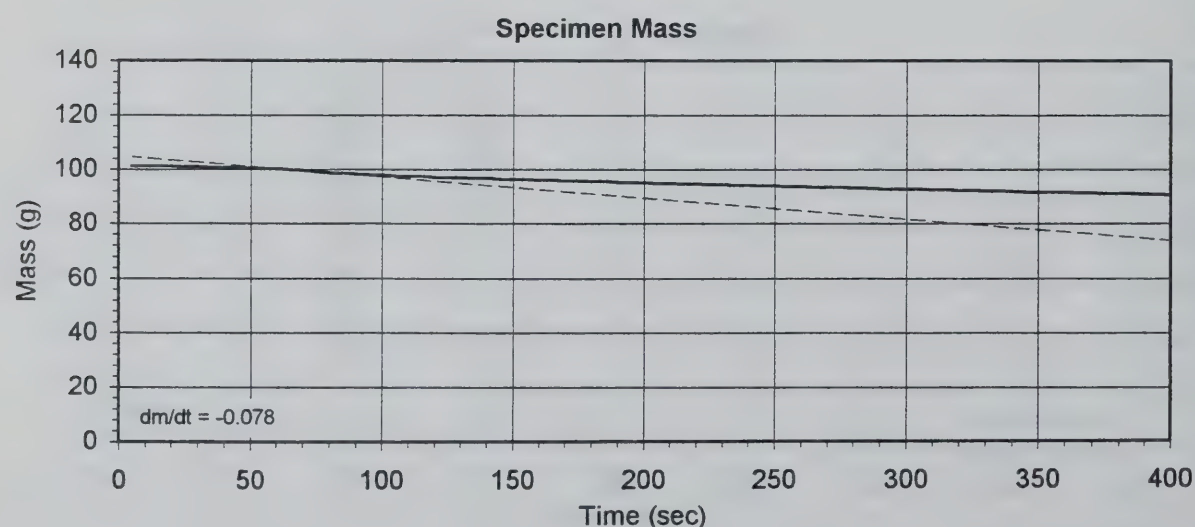




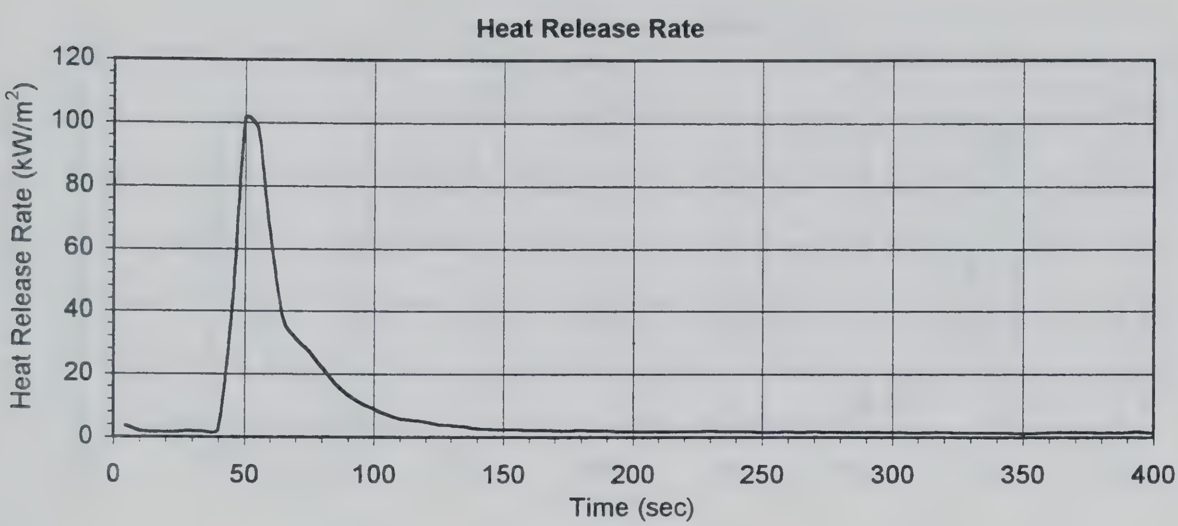
Cone Calorimeter Data R 4.02 Paper Faced Gypsum Board
40 kW/m^2, Test #5

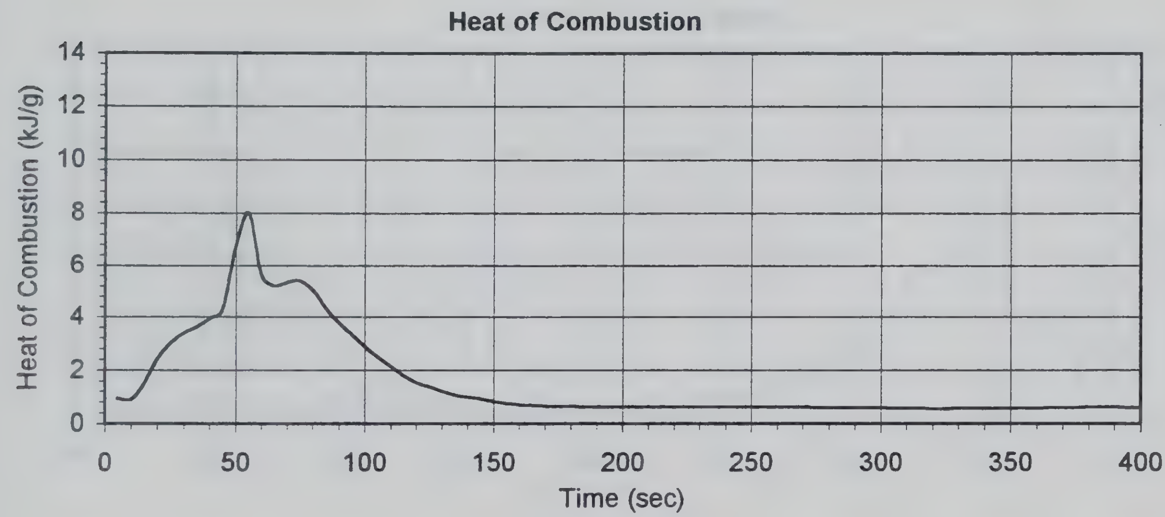


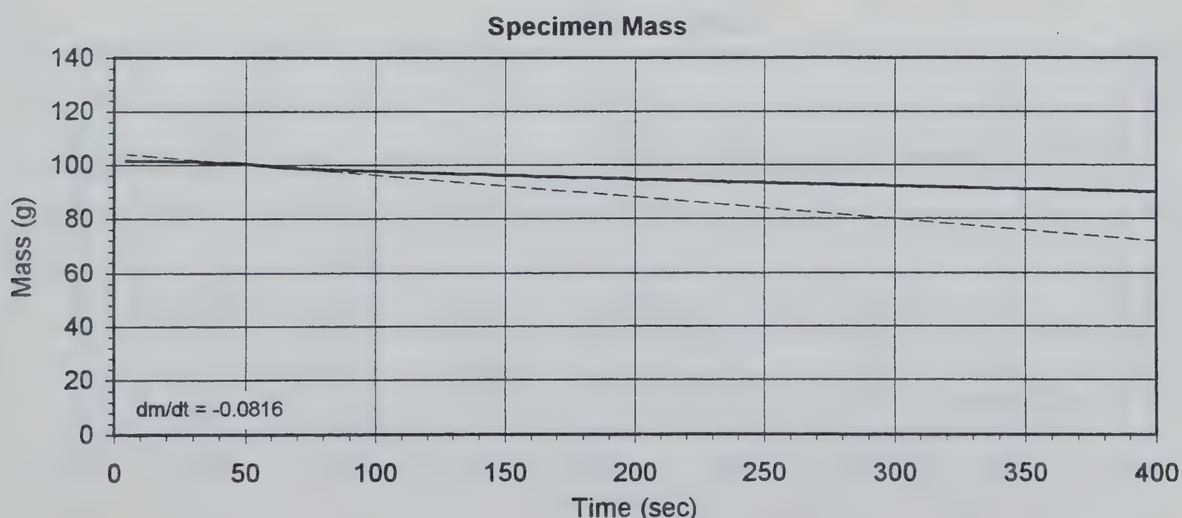




Cone Calorimeter Data R 4.02 Paper Faced Gypsum Board
50 kW/m^2, Test #1

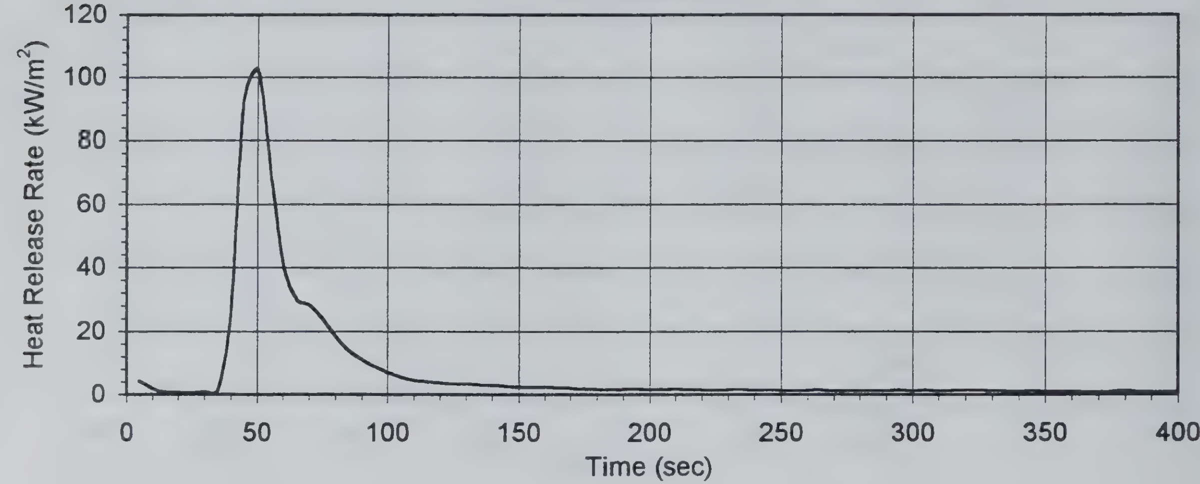




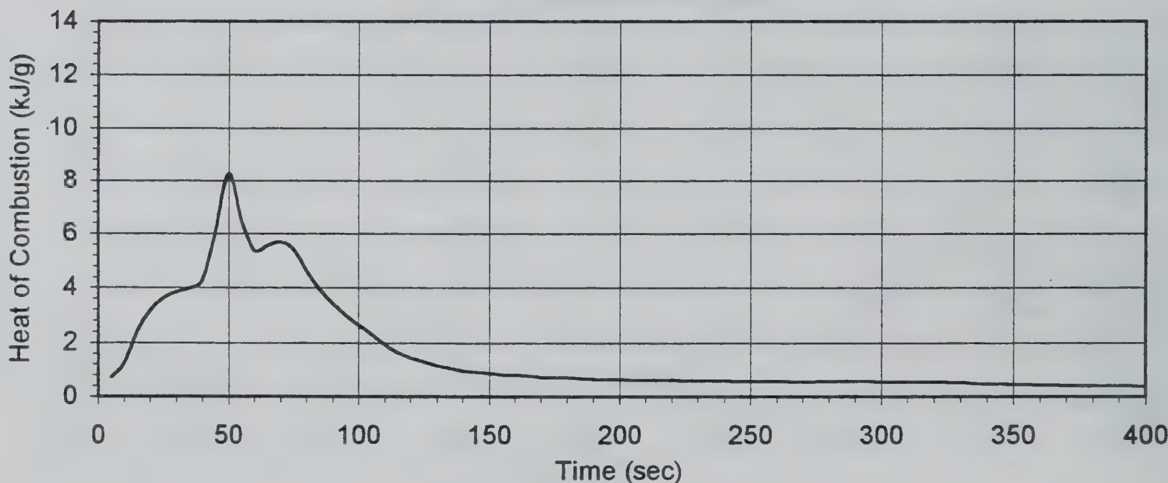


Cone Calorimeter Data R 4.02 Paper Faced Gypsum Board
50 kW/m², Test #2

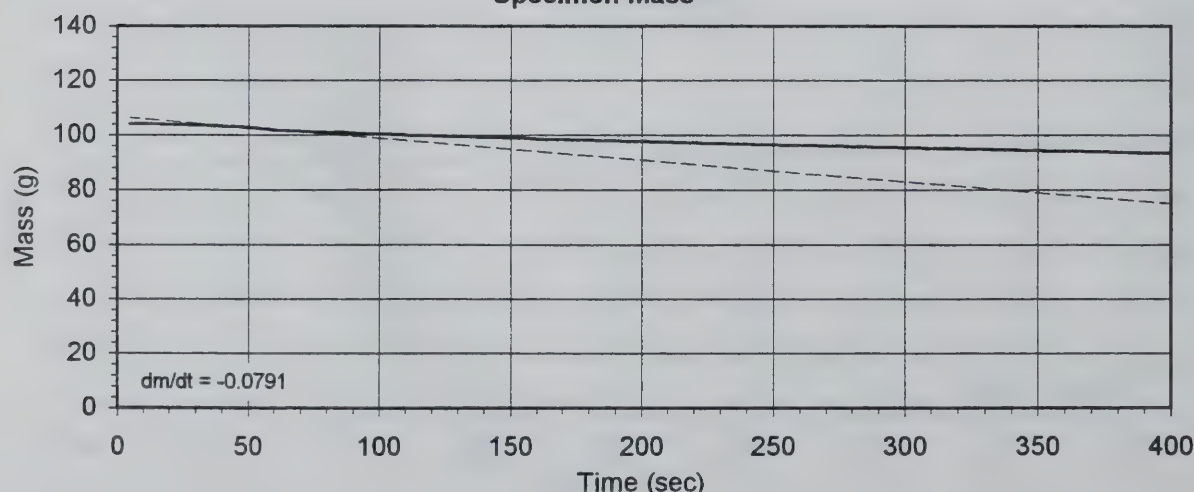
Heat Release Rate



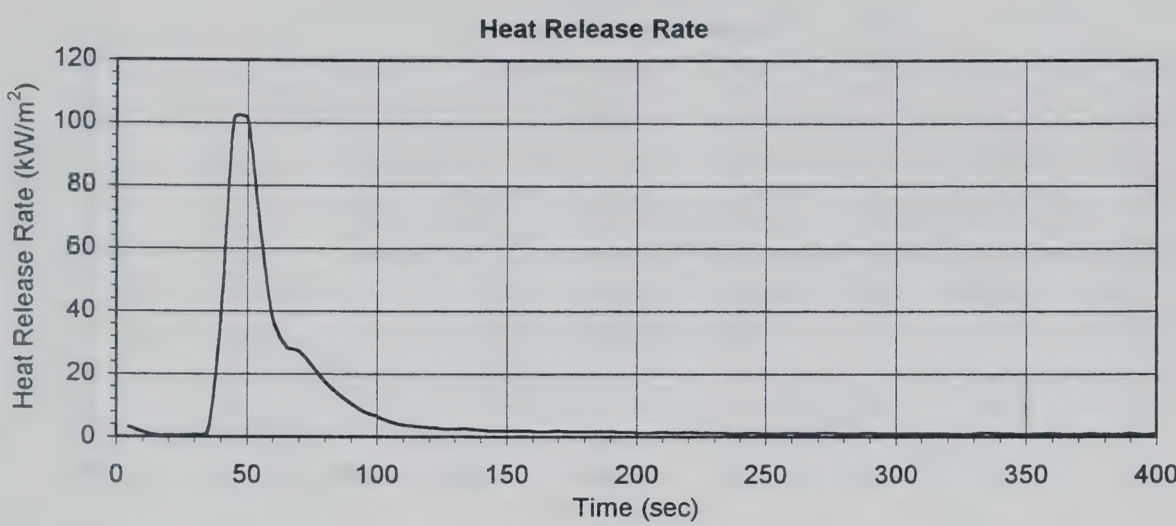
Heat of Combustion

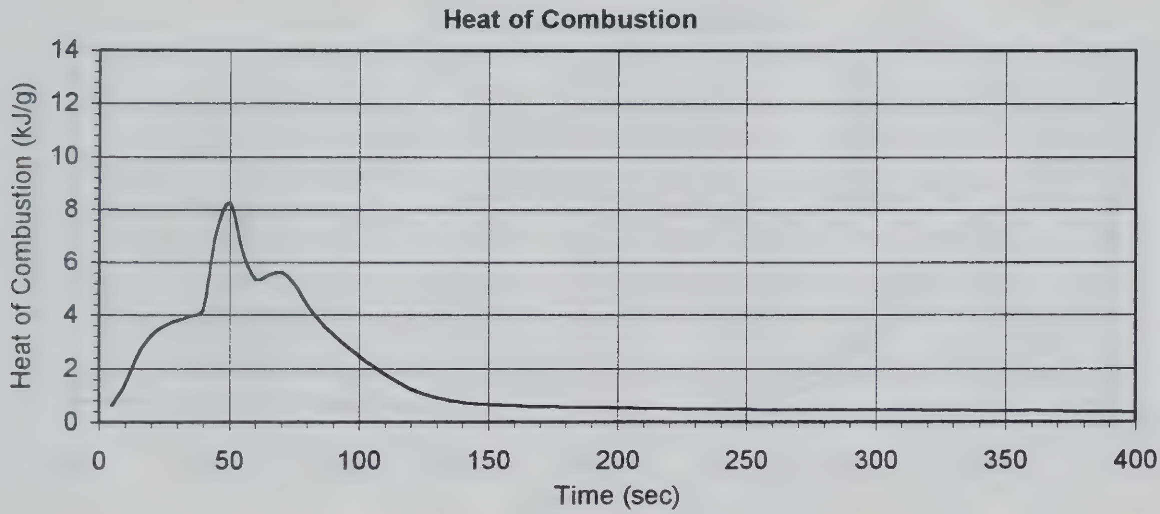


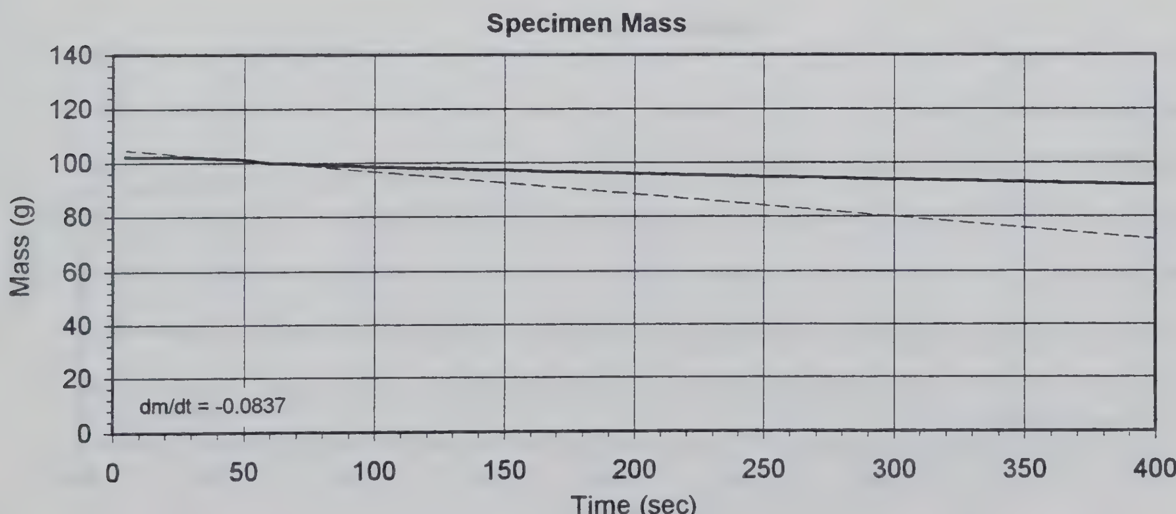
Specimen Mass



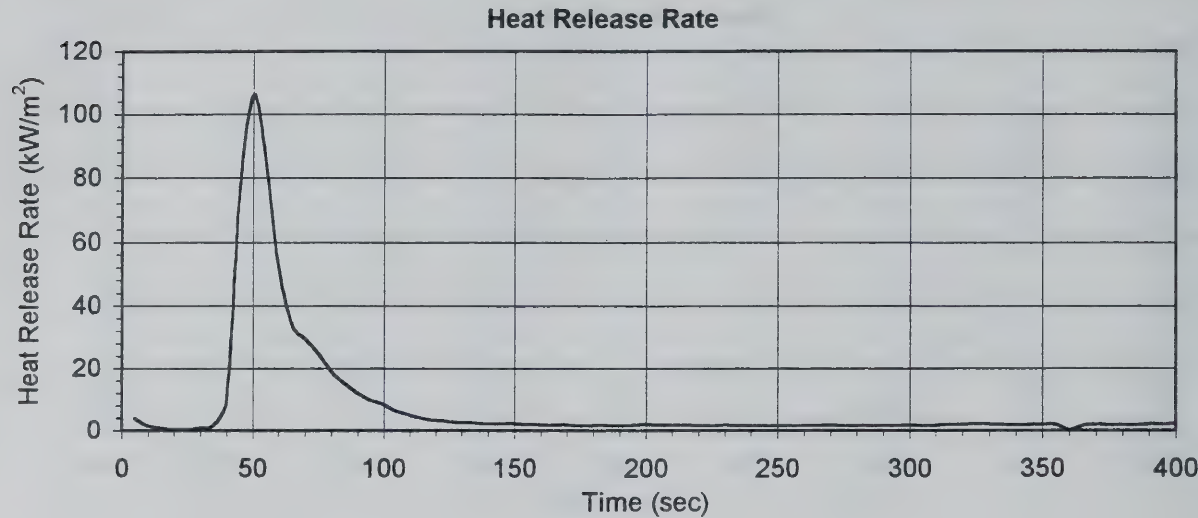
Cone Calorimeter Data R 4.02 Paper Faced Gypsum Board
50 kW/m², Test #3

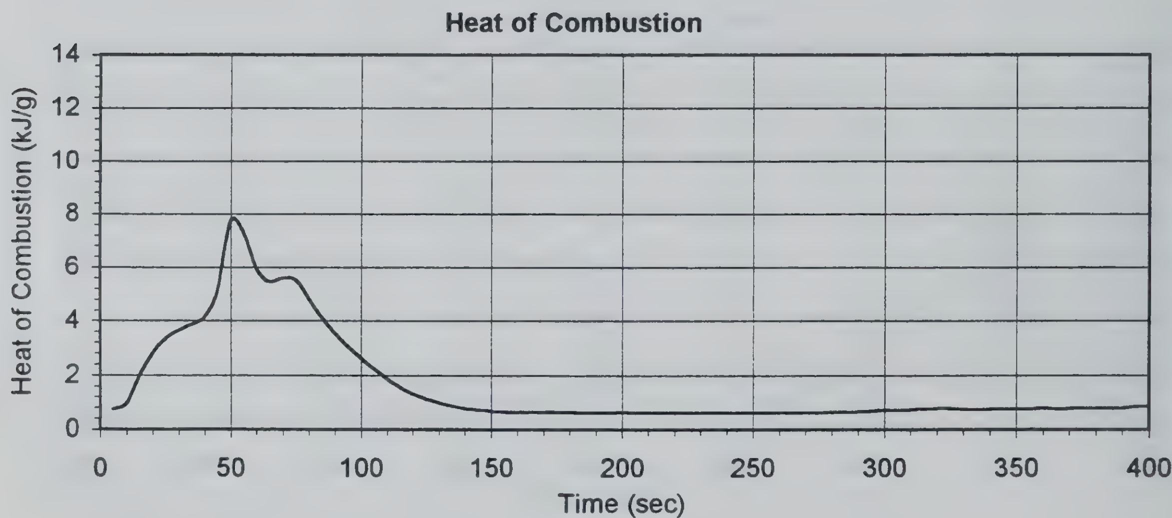


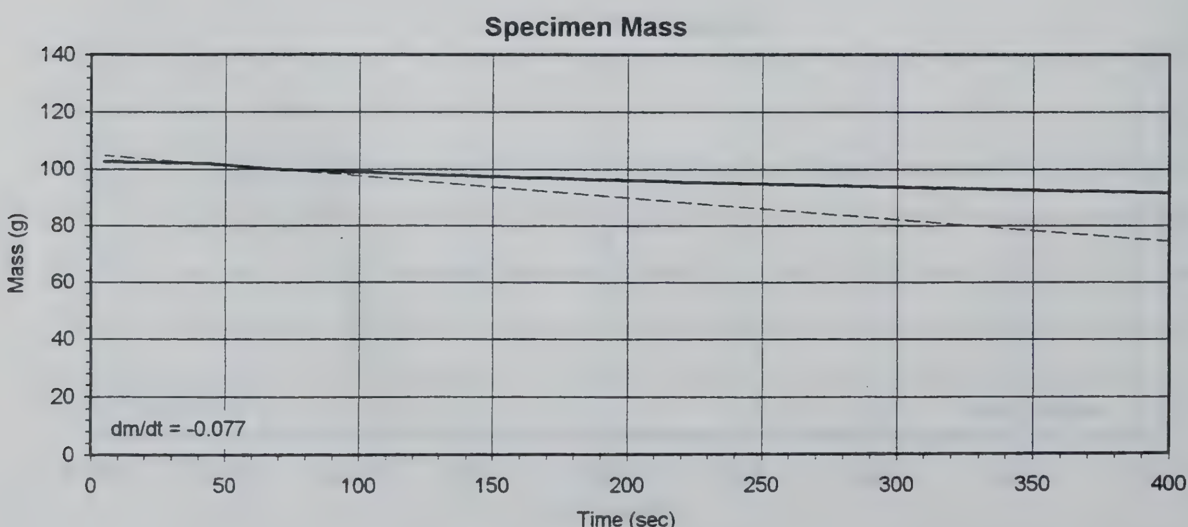




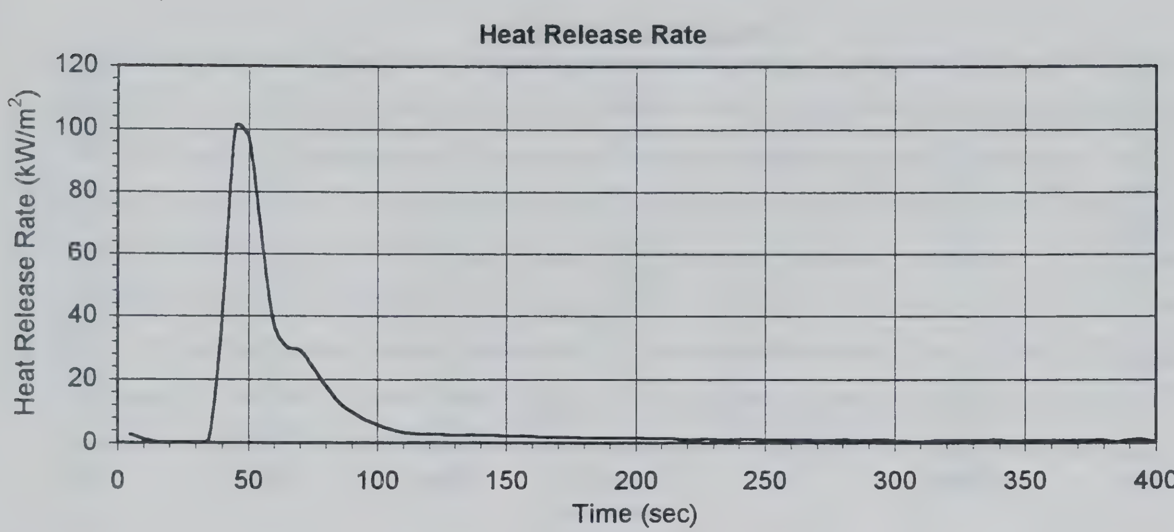
Cone Calorimeter Data R 4.02 Paper Faced Gypsum Board
50 kW/m^2, Test #4

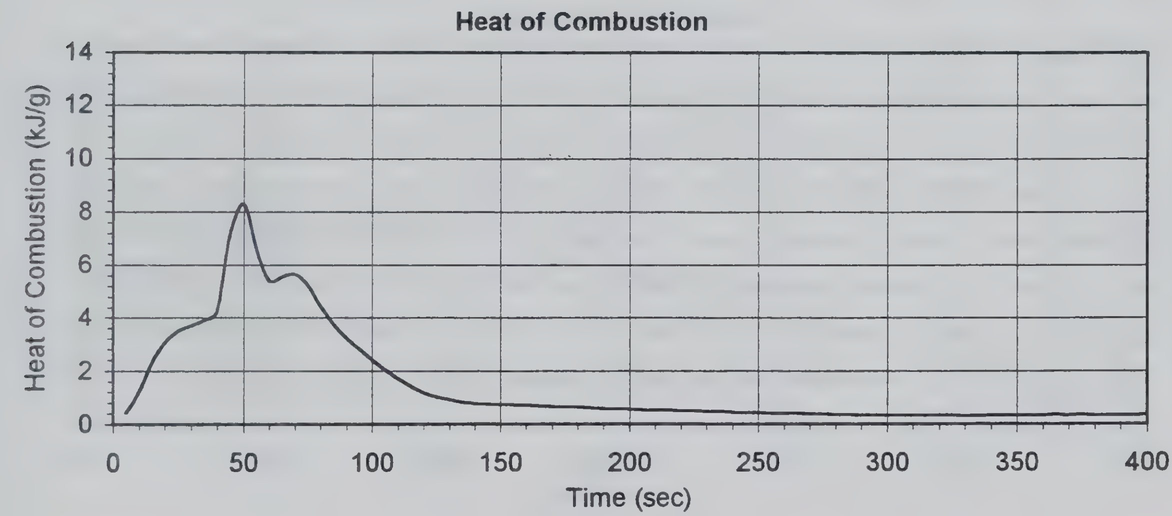


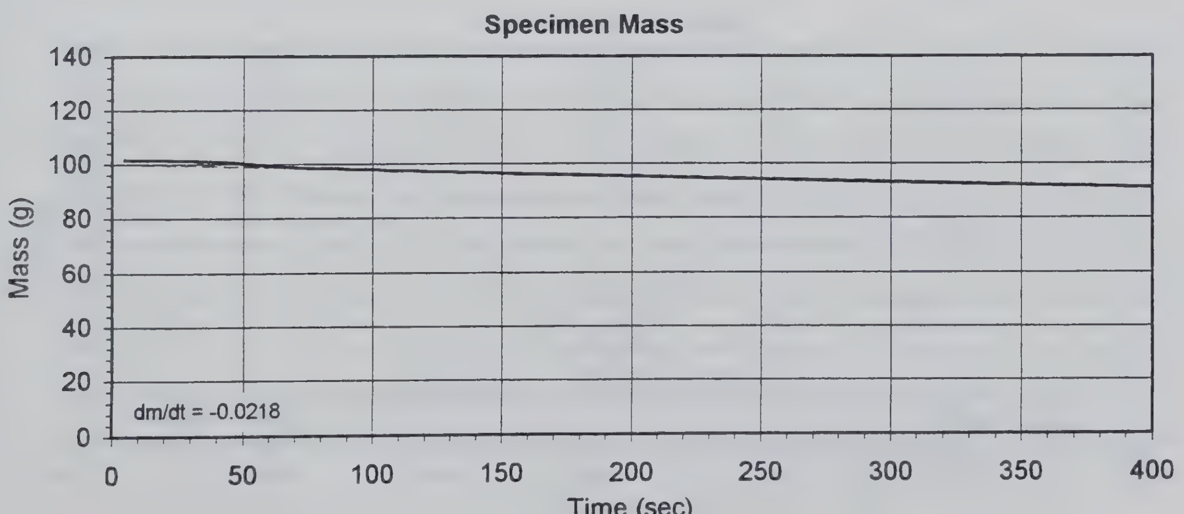




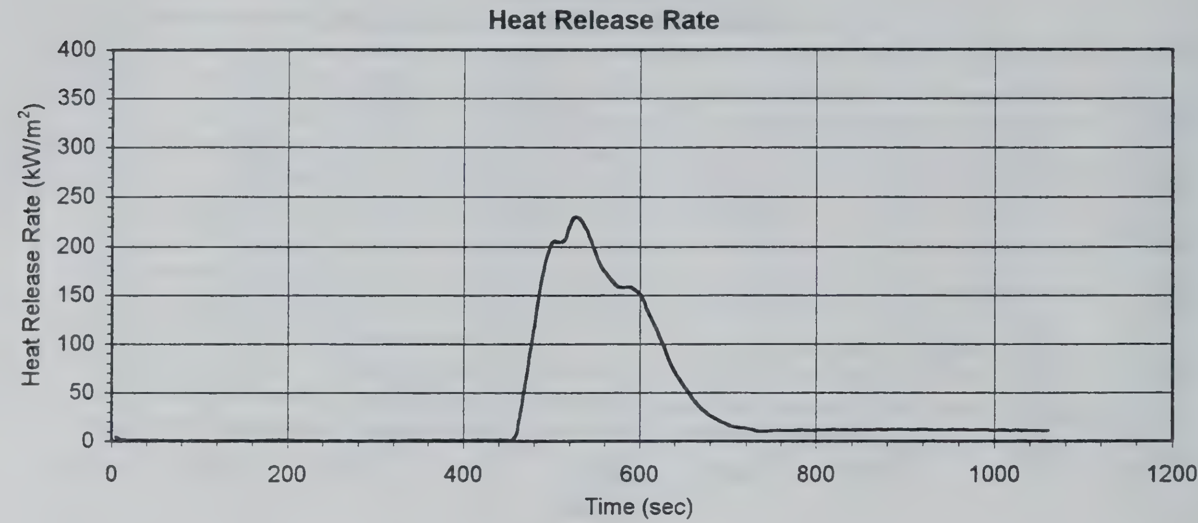
Cone Calorimeter Data R 4.02 Paper Faced Gypsum Board
50kW/m^2, Test #5

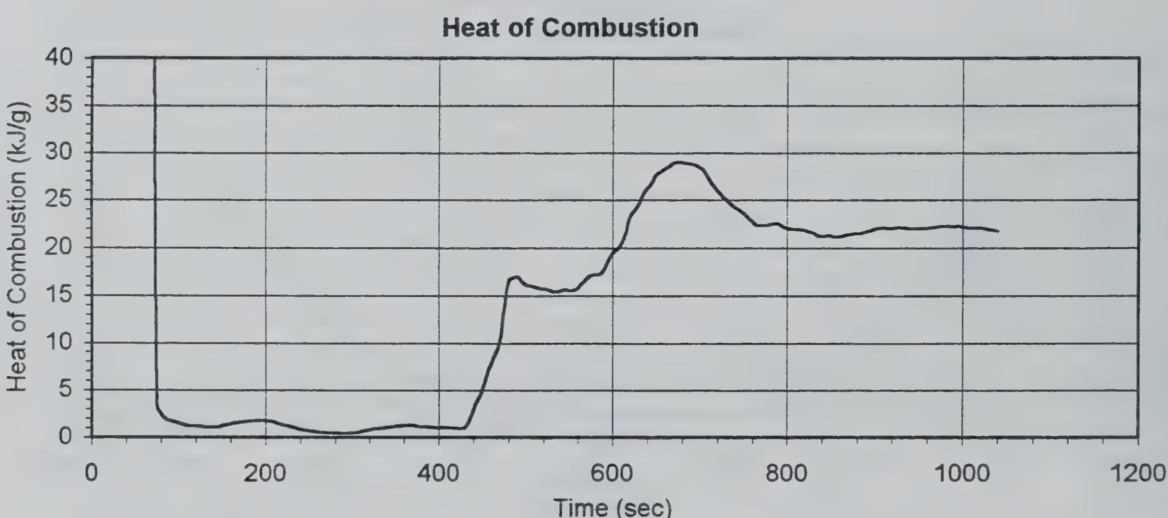


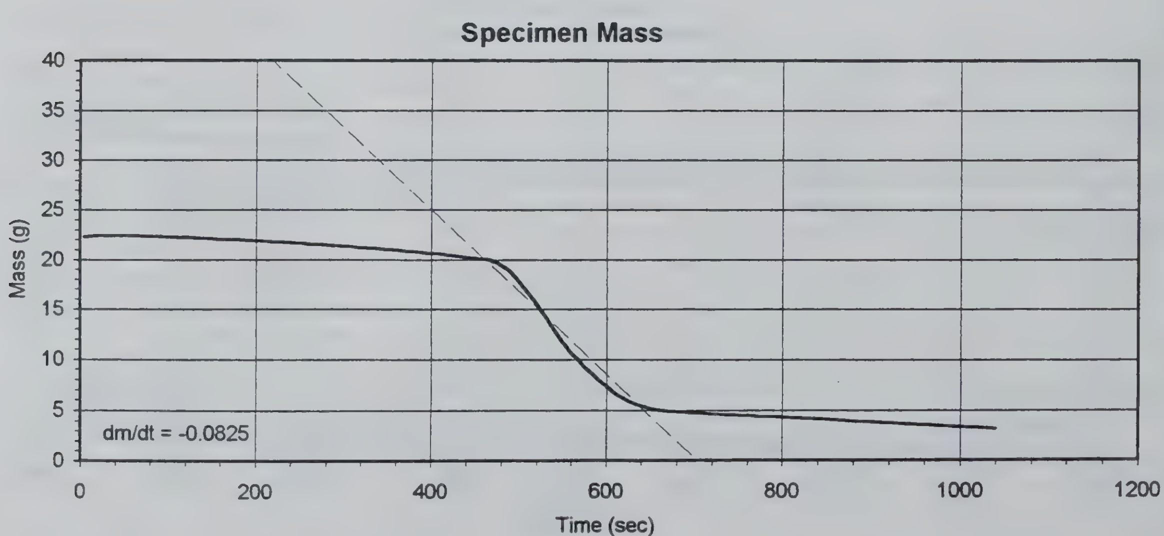




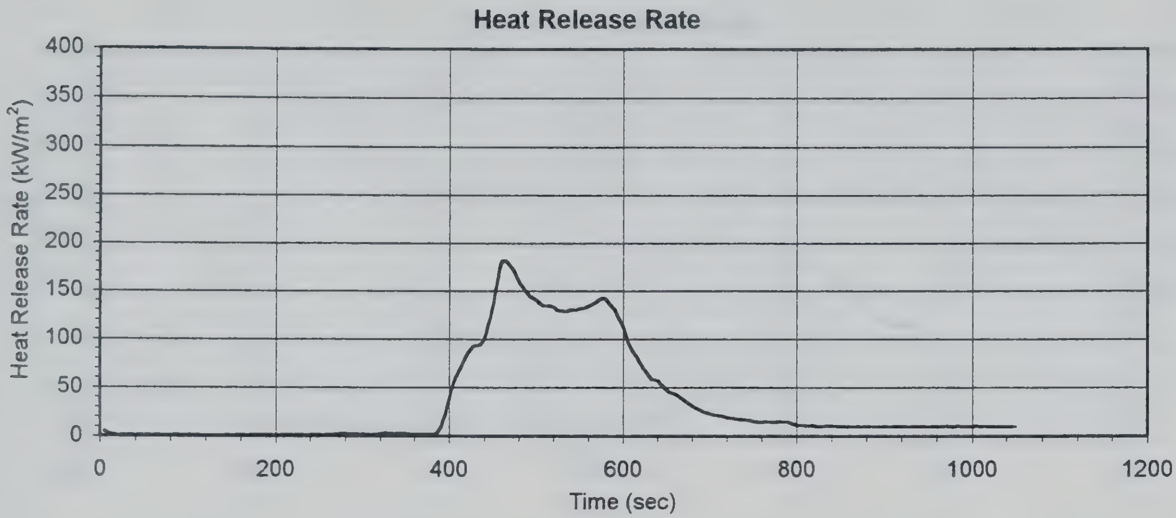
Cone Calorimeter Data R 4.03 Polyurethane Foam Panel with Aluminum Faced Paper
50 kW/m^2, Test #1

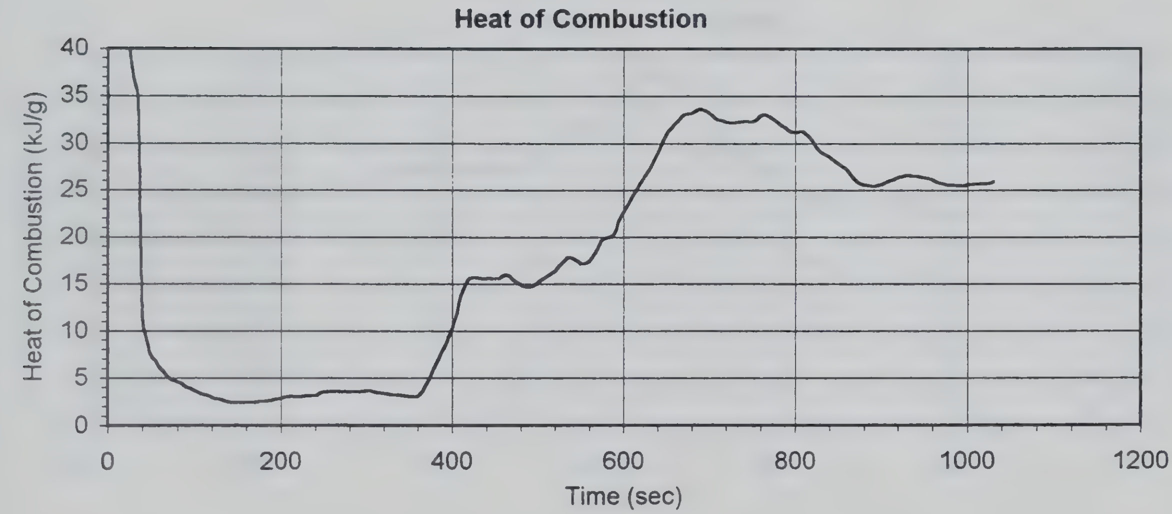


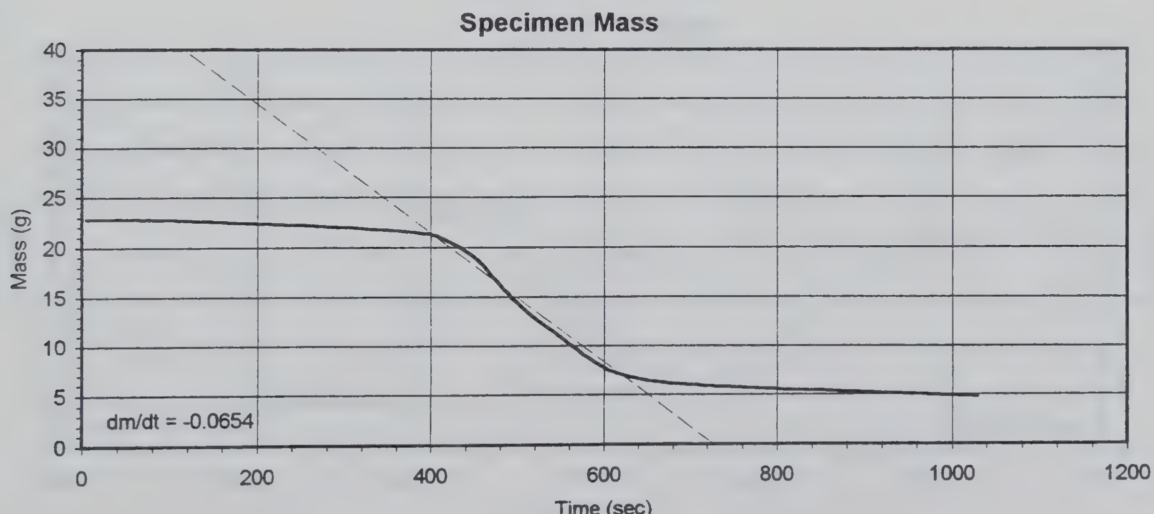




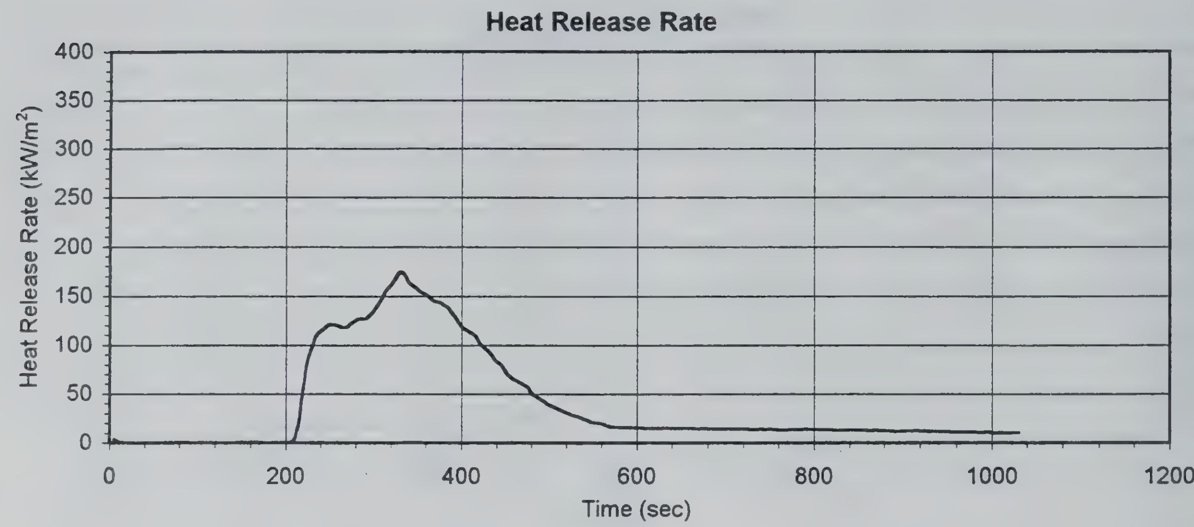
Cone Calorimeter Data R 4.03 Polyurethane Foam Panel with Aluminum Faced Paper
50 kW/m^2, Test #2

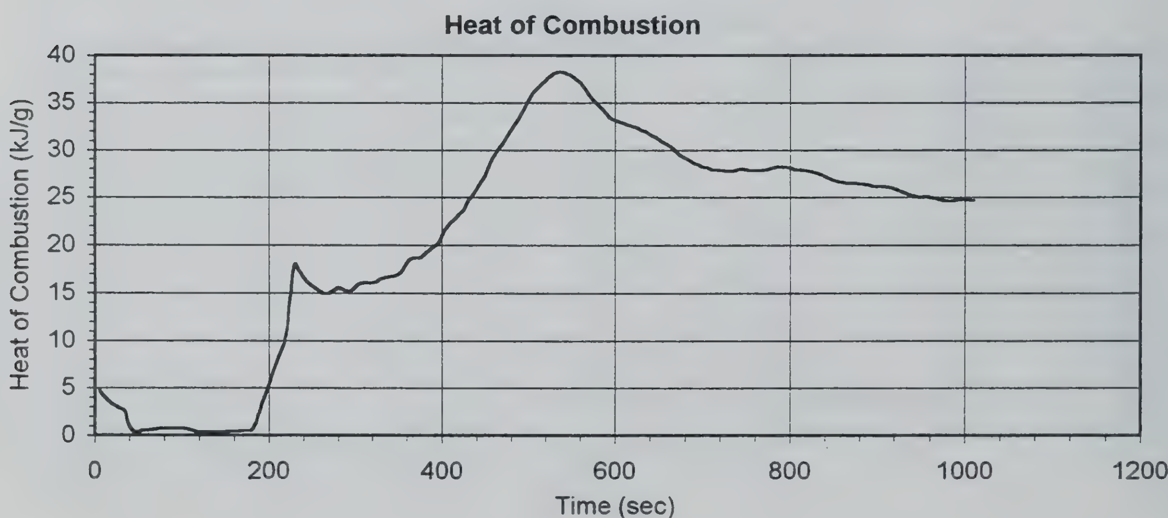


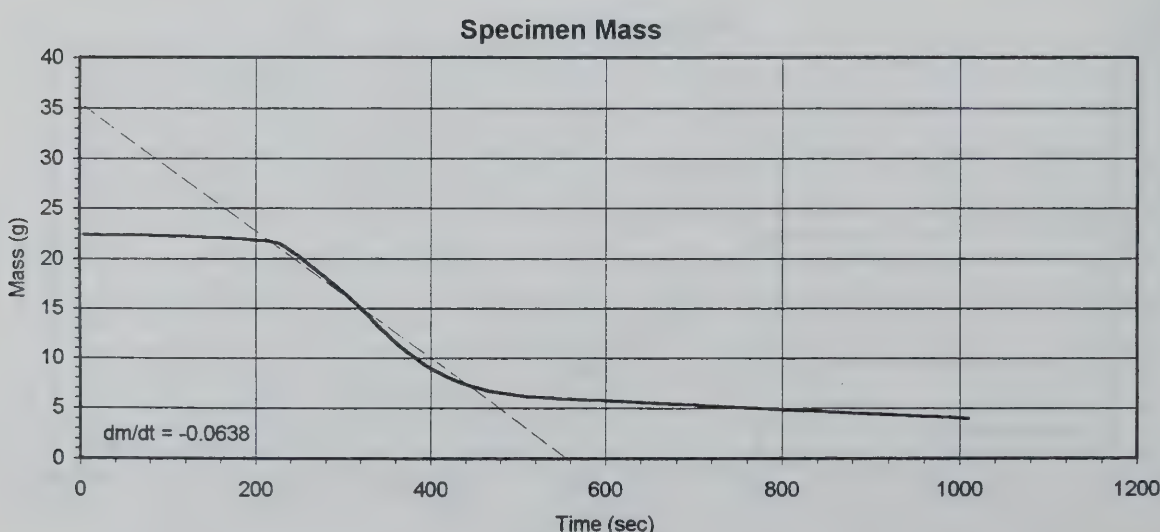




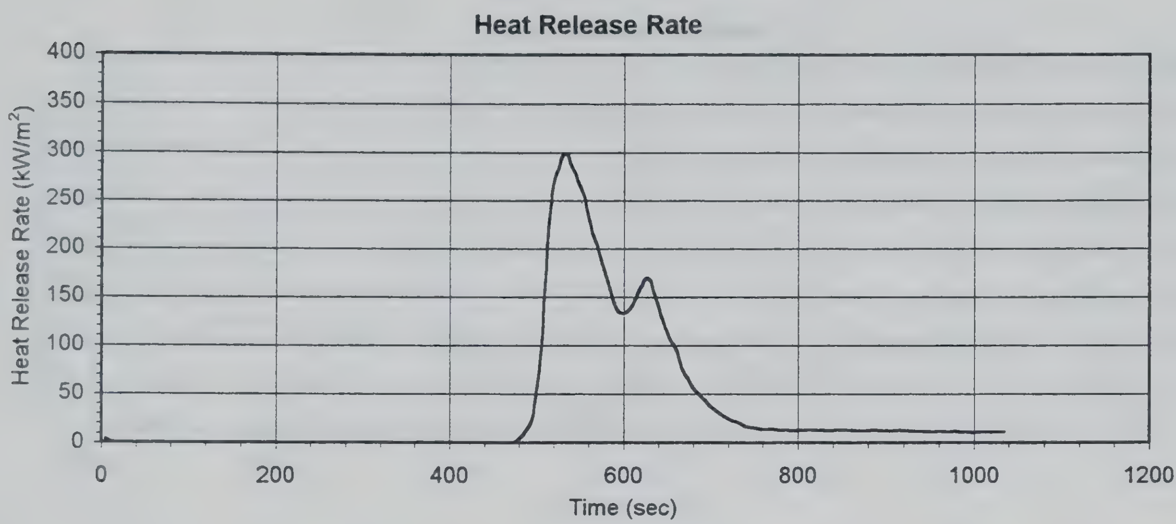
Cone Calorimeter Data R 4.03 Polyurethane Foam Panel with Aluminum Faced Paper
50 kW/m^2, Test #3

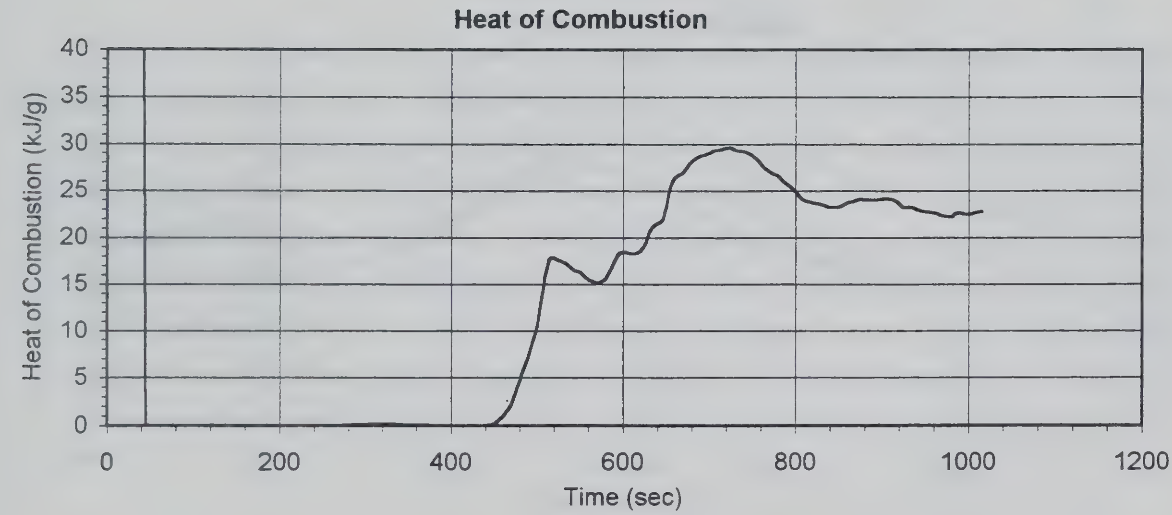


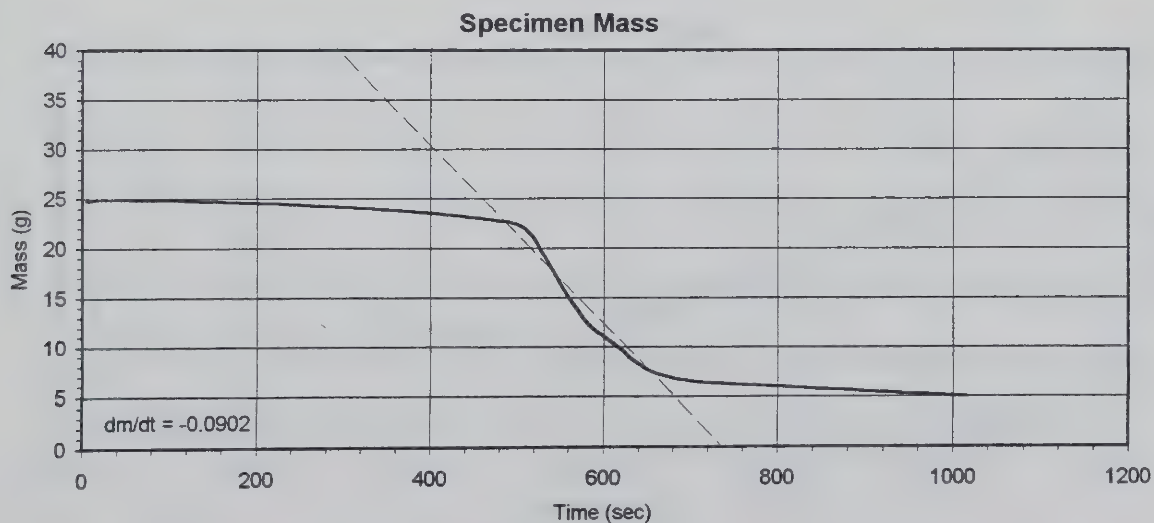




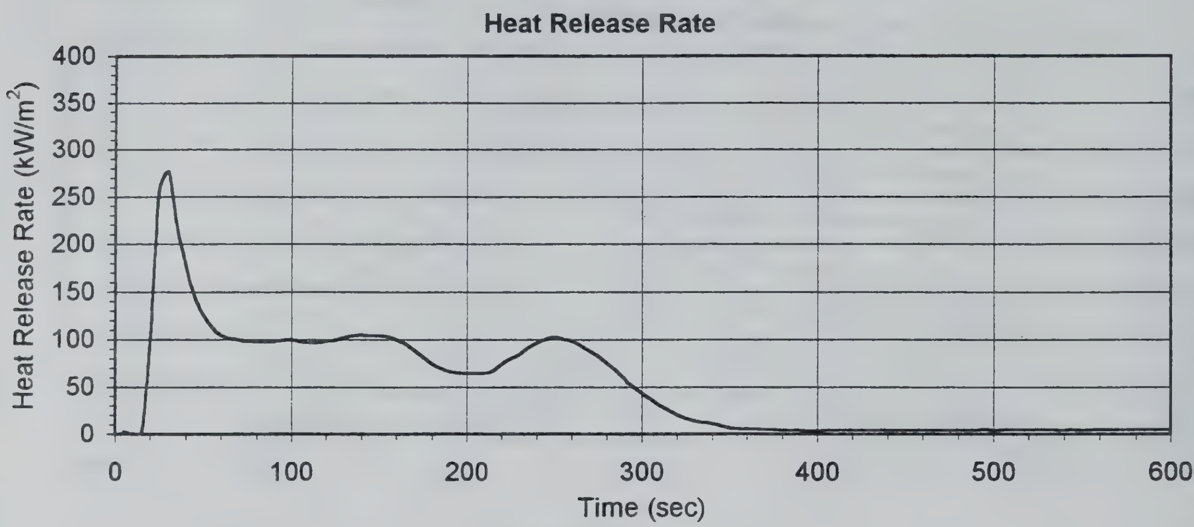
Cone Calorimeter Data R 4.03 Polyurethane Foam Panel with Aluminum Faced Paper
50 kW/m^2, Test #4

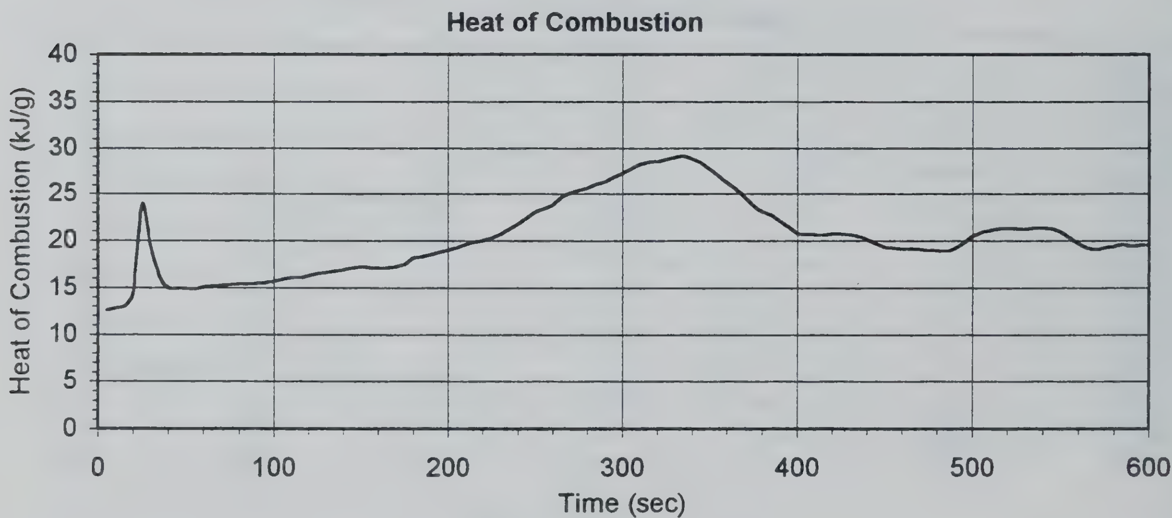


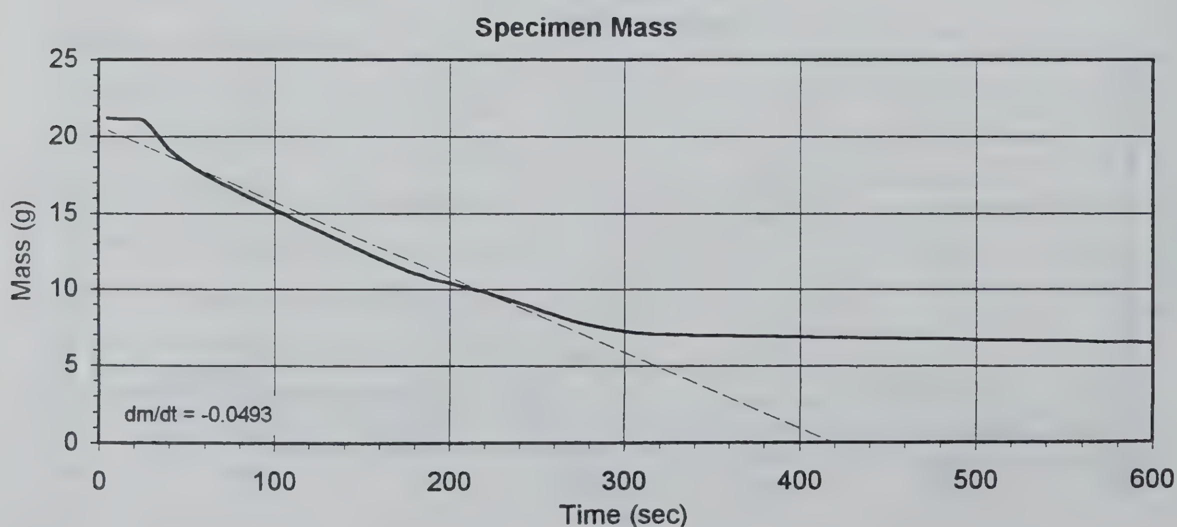




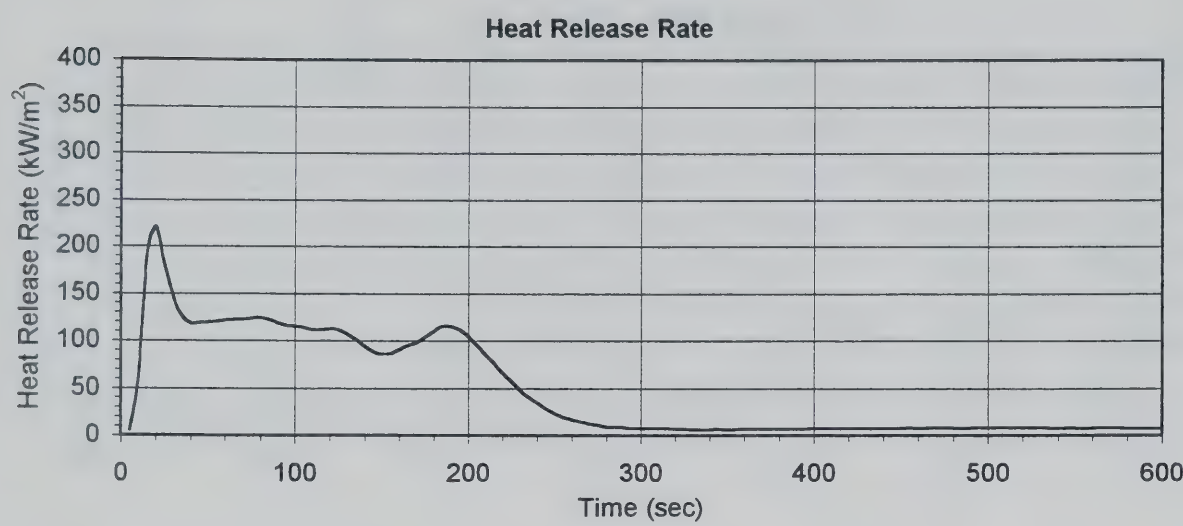
Cone Calorimeter Data R 4.04 Polyurethane with Paper Backing
25 kW/m², Test #1

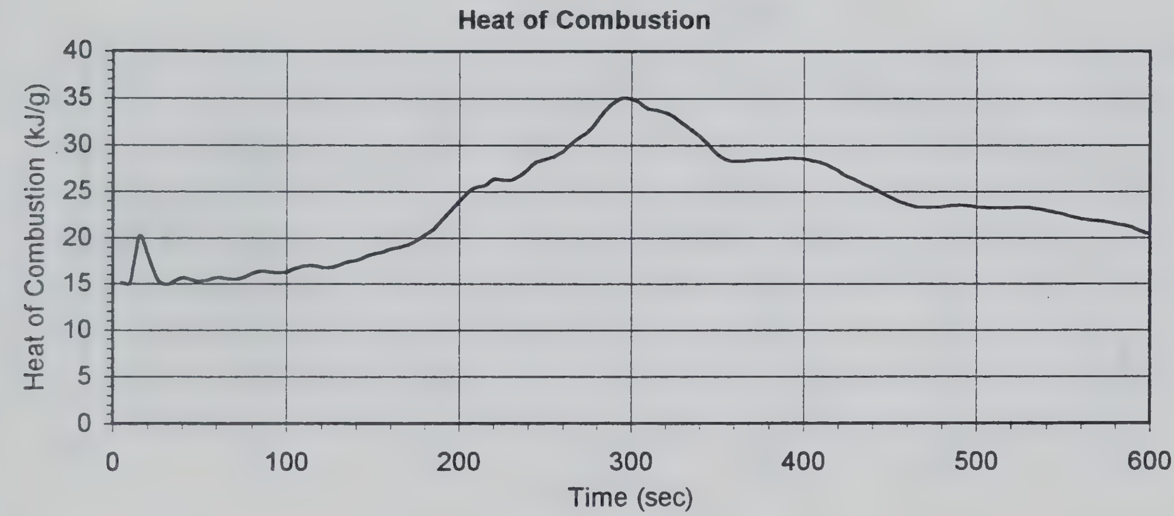


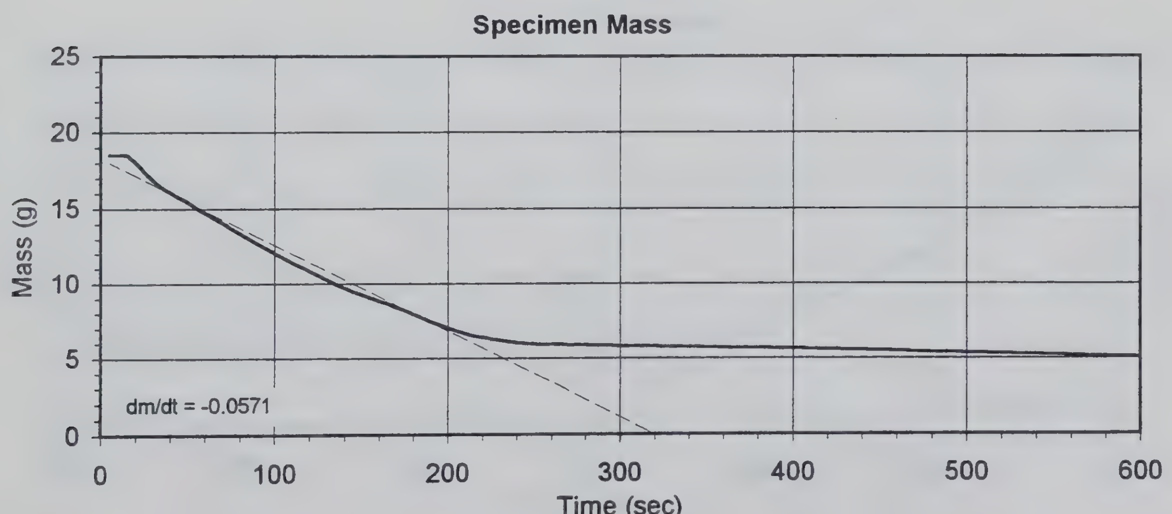




Cone Calorimeter Data R 4.04 Polyurethane with Paper Backing
25 kW/m^2, Test #2

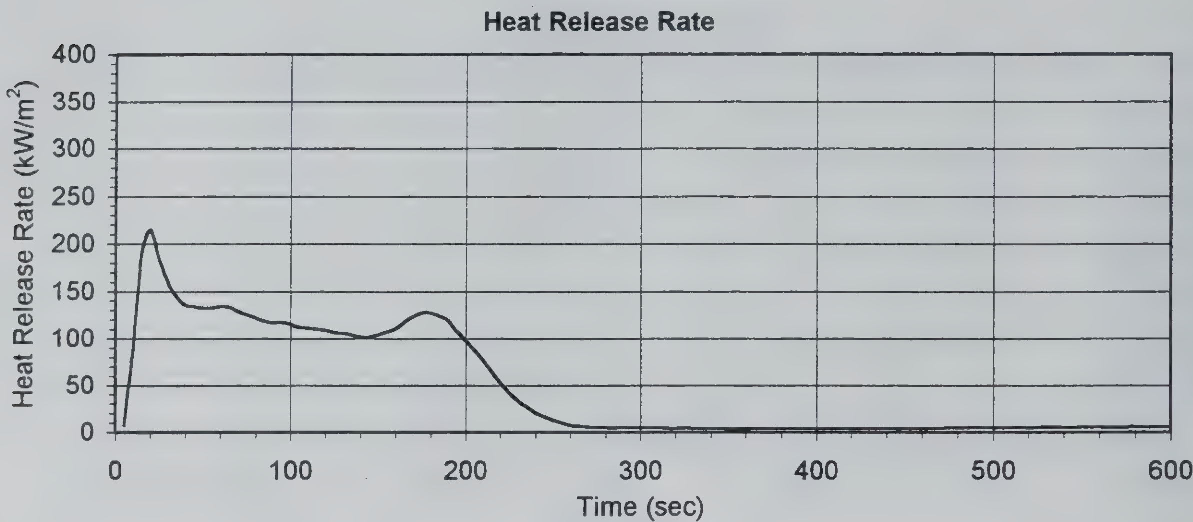


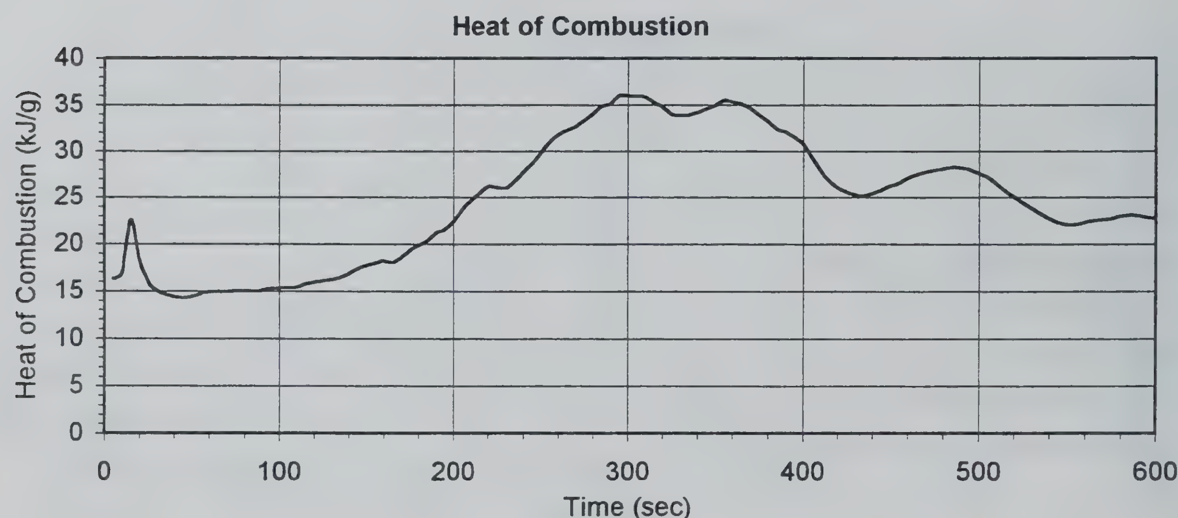


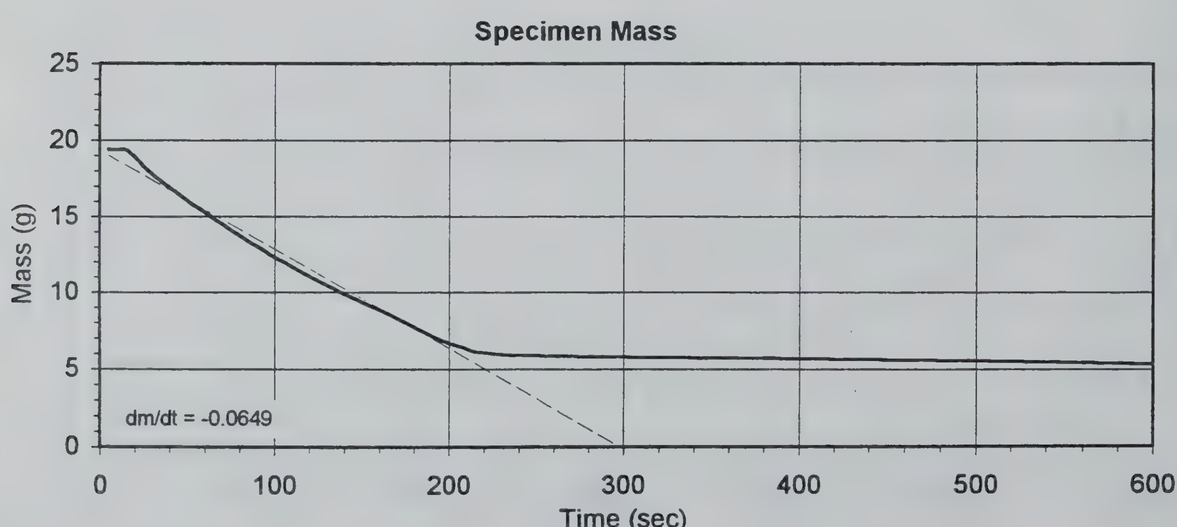


Cone Calorimeter Data R 4.04 Polyurethane with Paper Backing

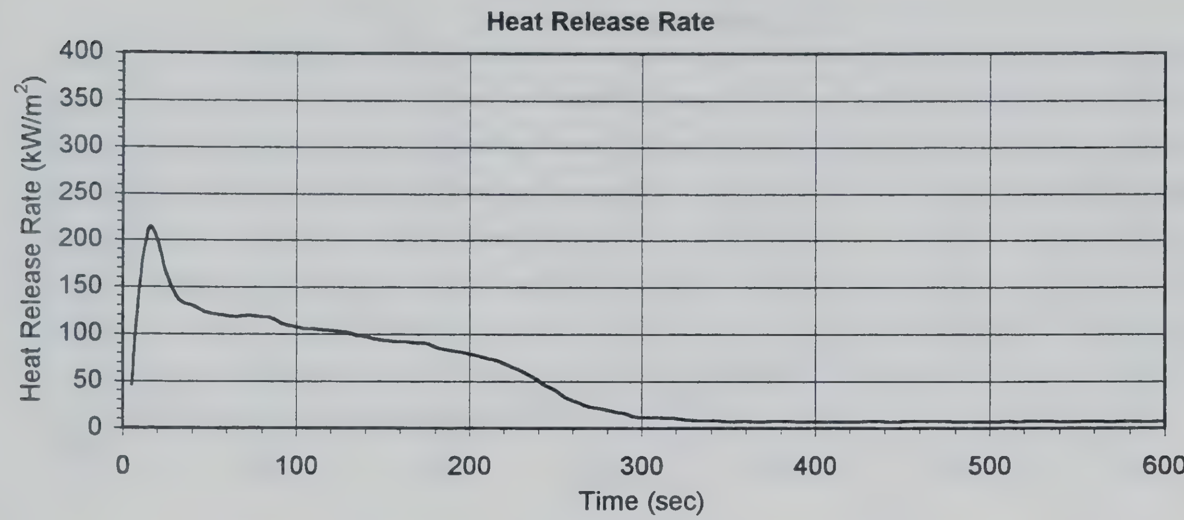
25 kW/m², Test #3

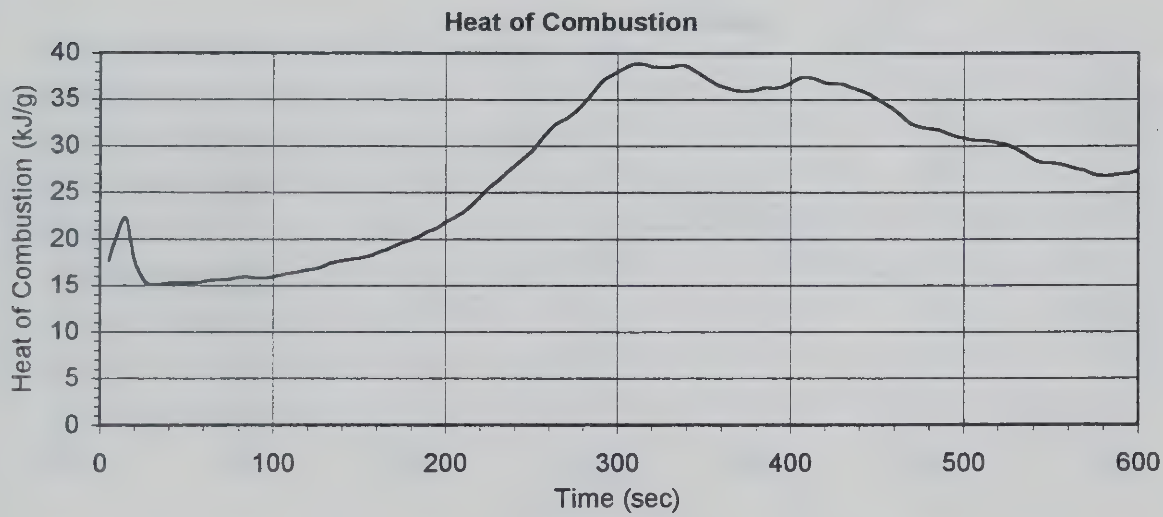


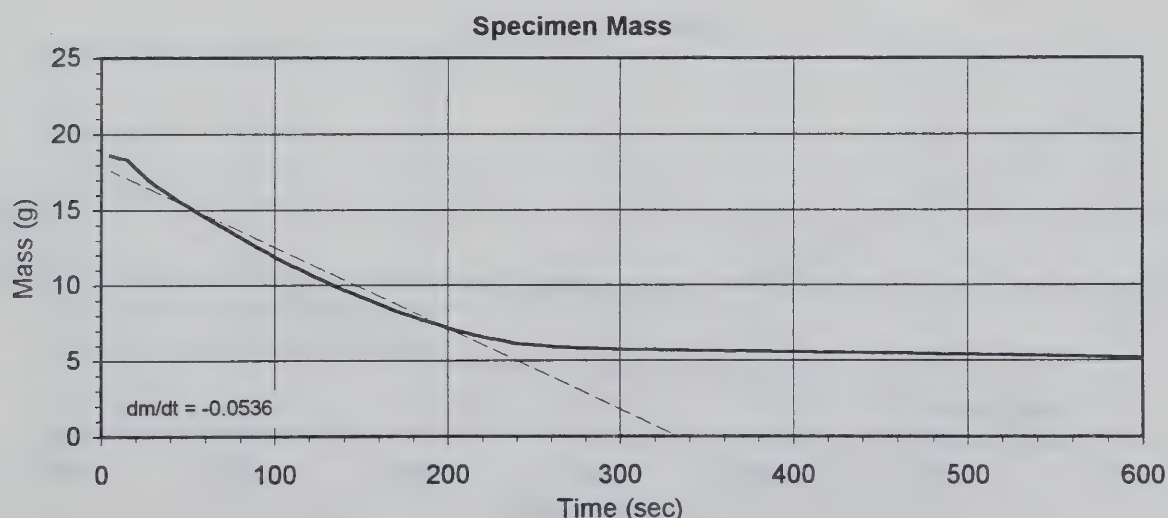




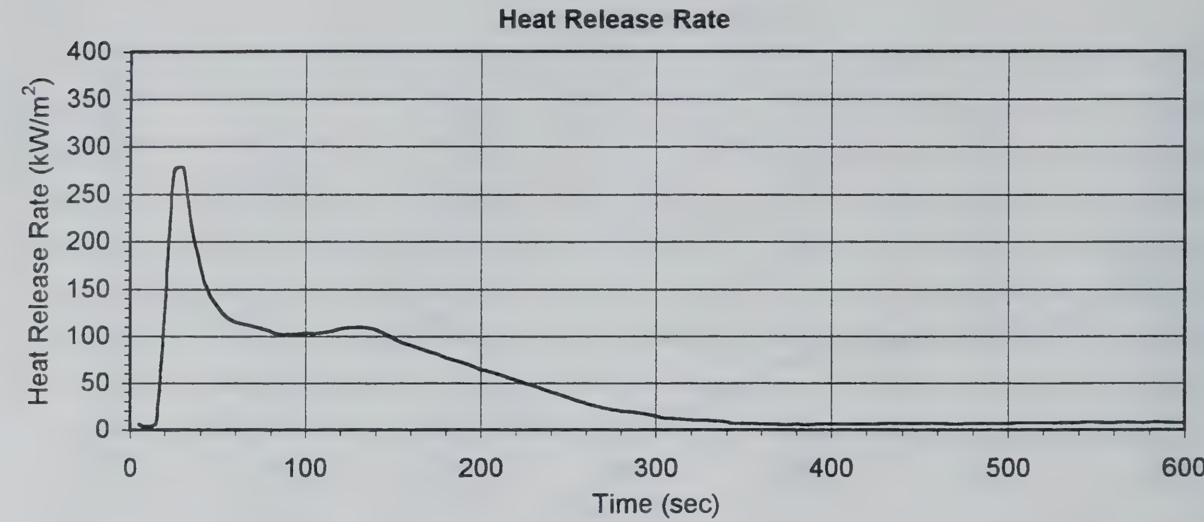
Cone Calorimeter Data R 4.04 Polyurethane with Paper Backing
25 kW/m^2, Test #4

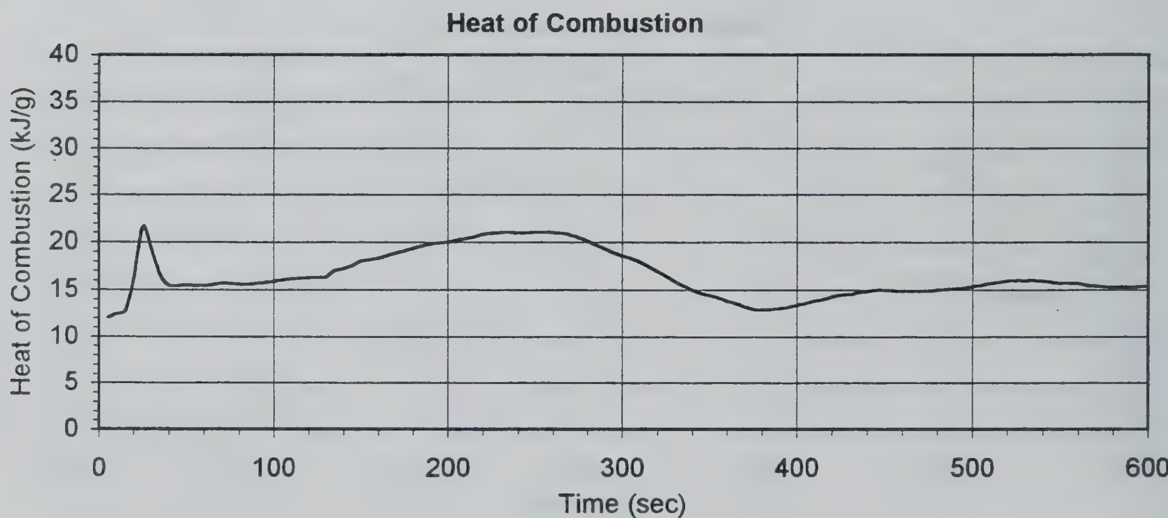


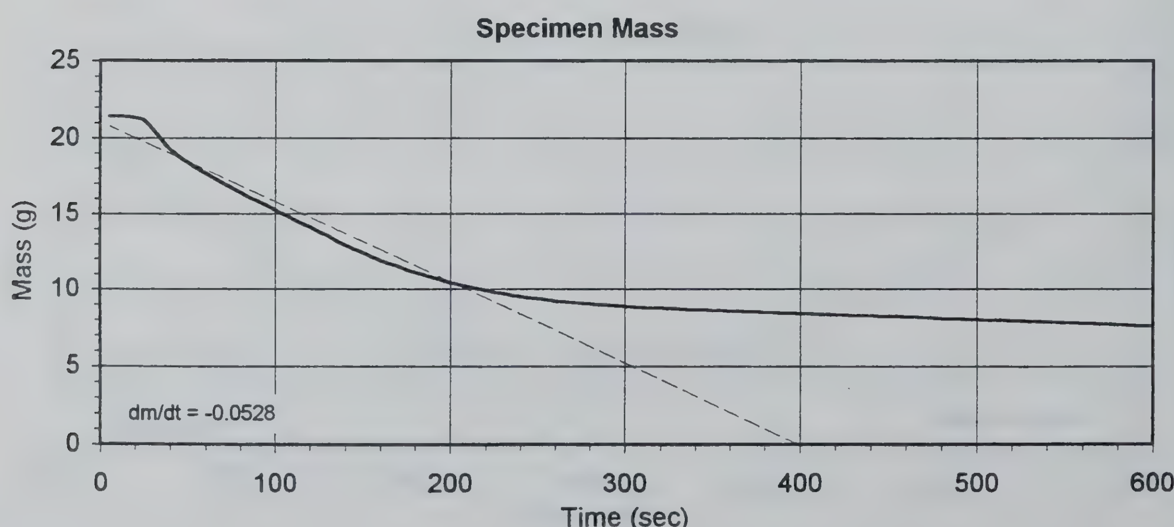




Cone Calorimeter Data R 4.04 Polyurethane with Paper Backing
25 kW/m^2, Test #5

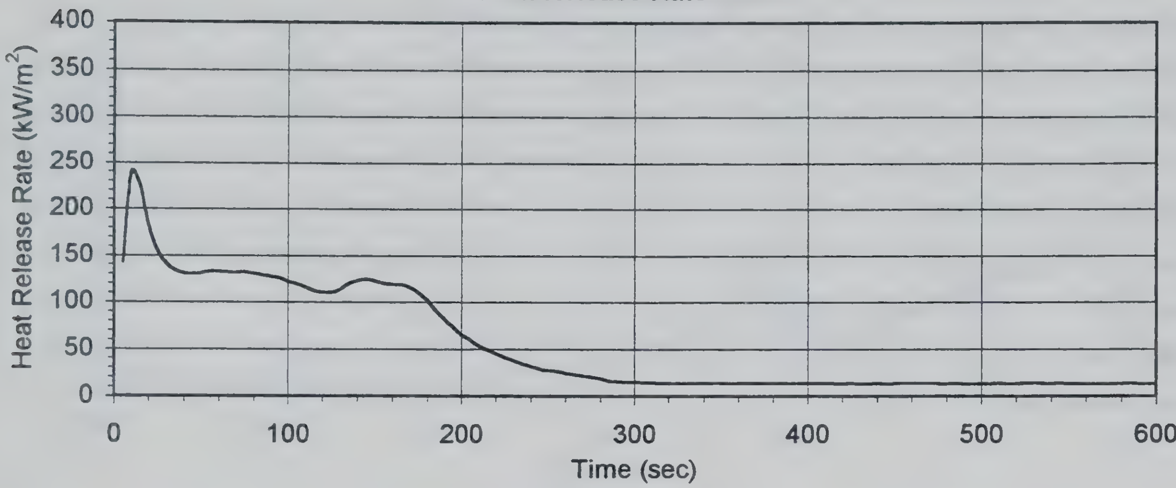




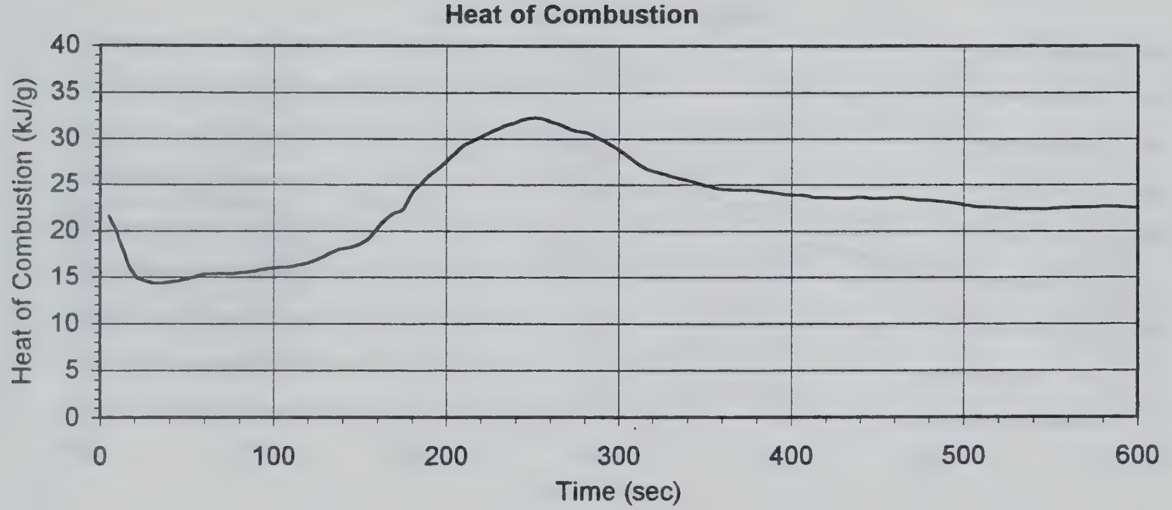


Cone Calorimeter Data R 4.04 Polyurethane with Paper Backing
35 kW/m^2, Test #1

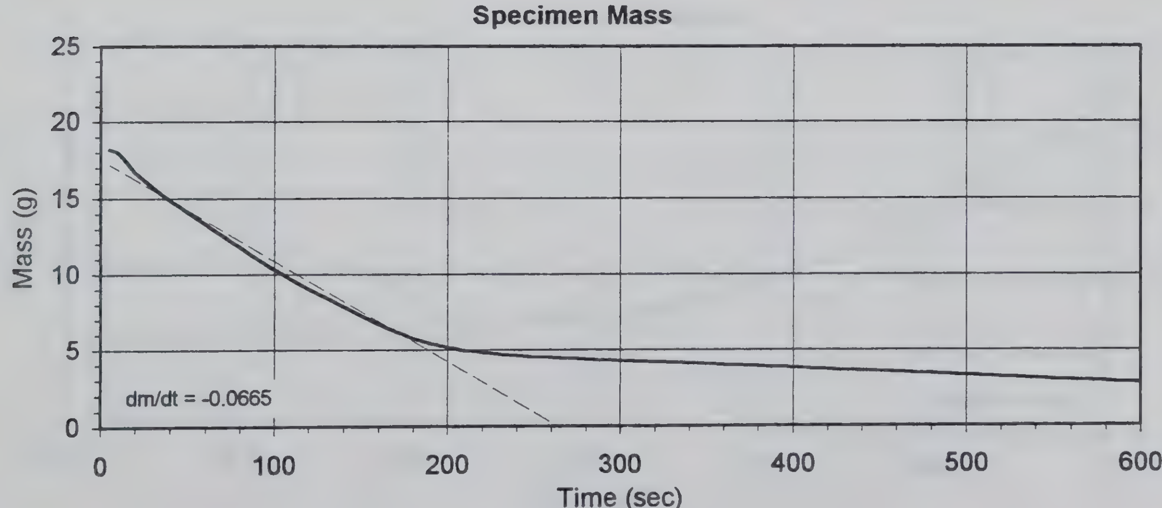
Heat Release Rate



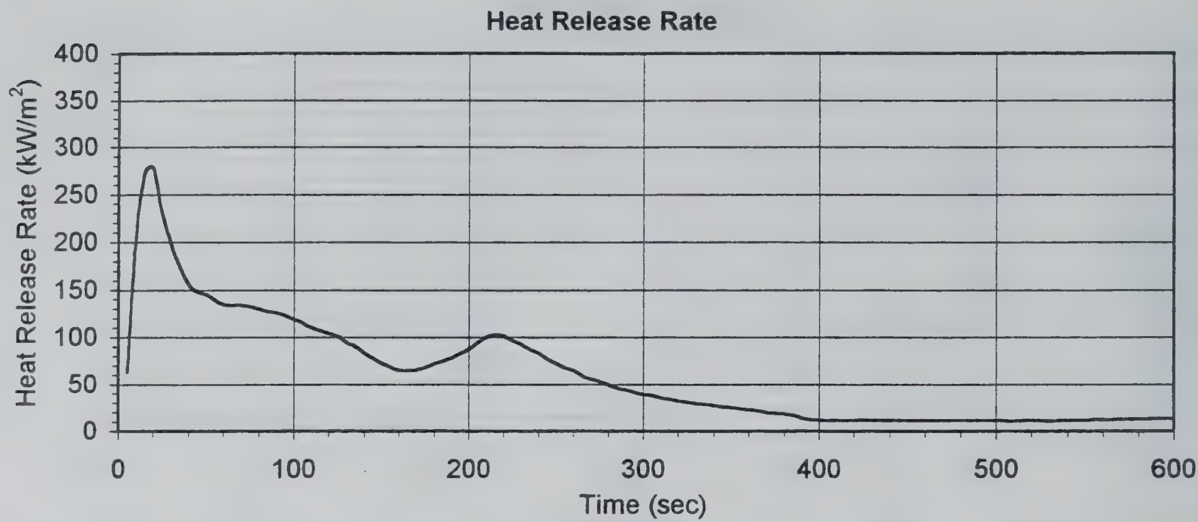
Heat of Combustion

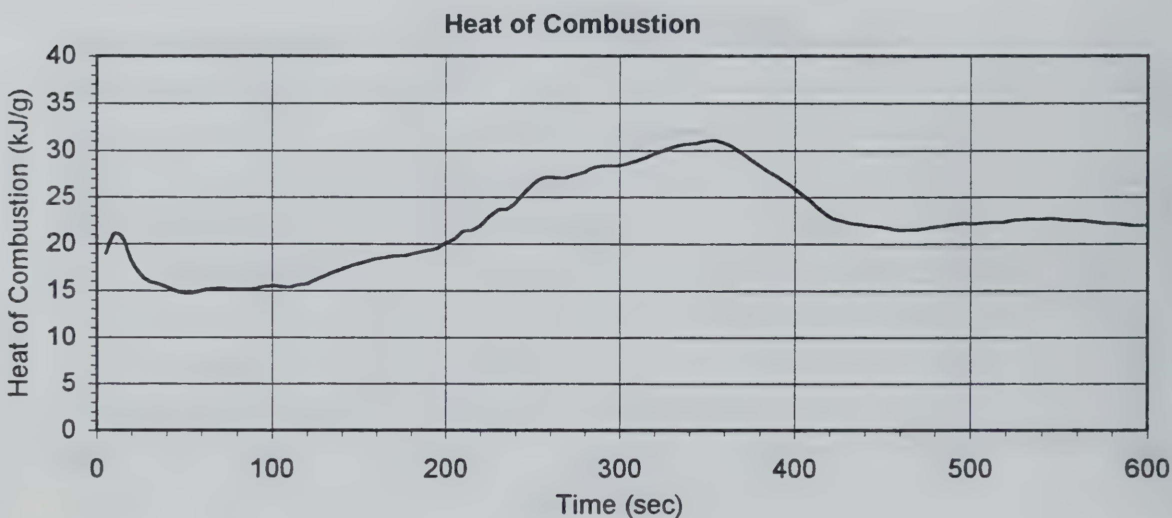


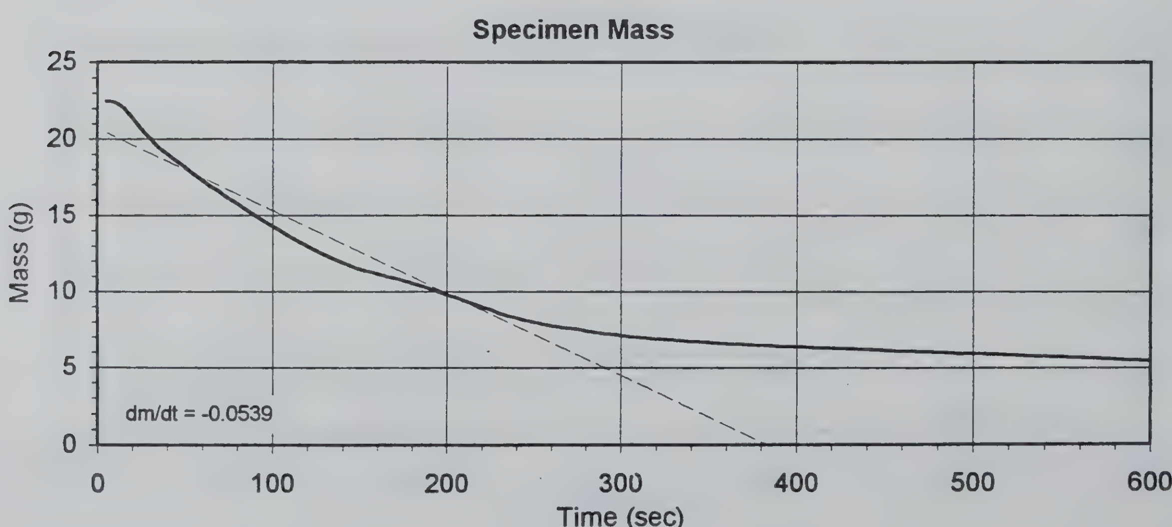
Specimen Mass



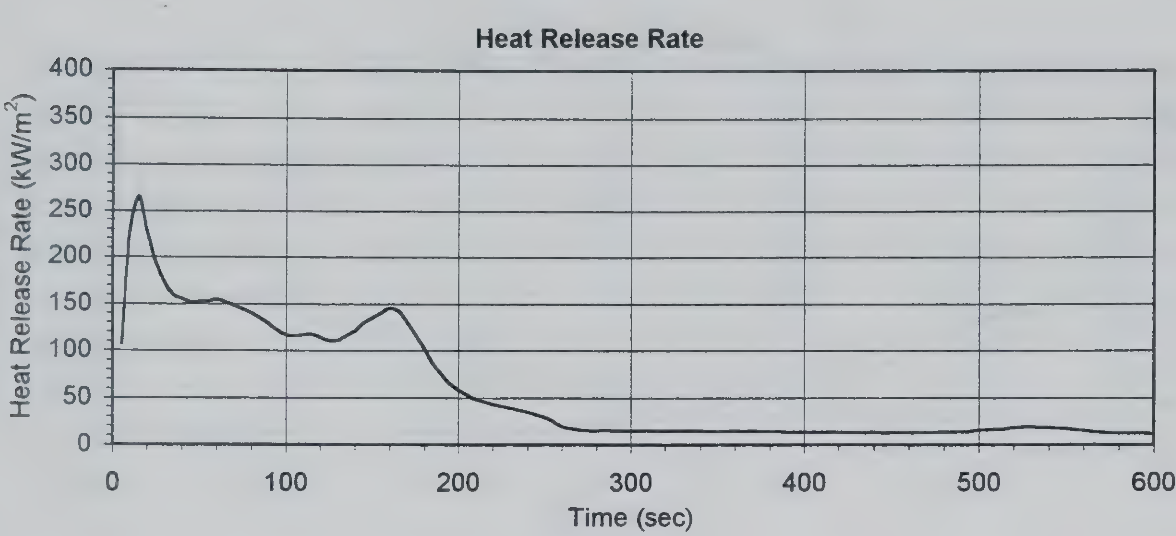
Cone Calorimeter Data R 4.04 Polyurethane with Paper Backing
35 kW/m^2, Test #2

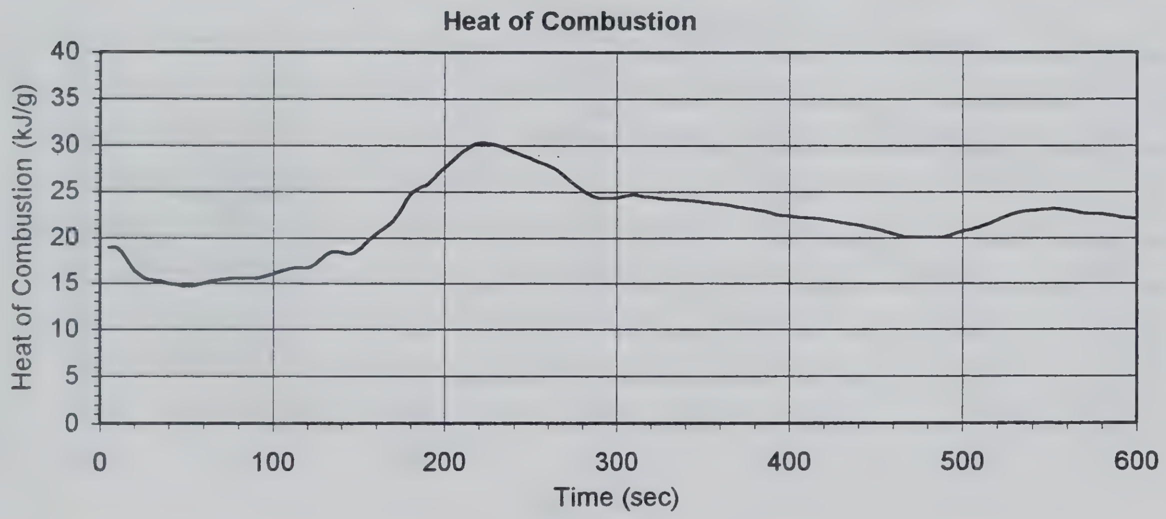


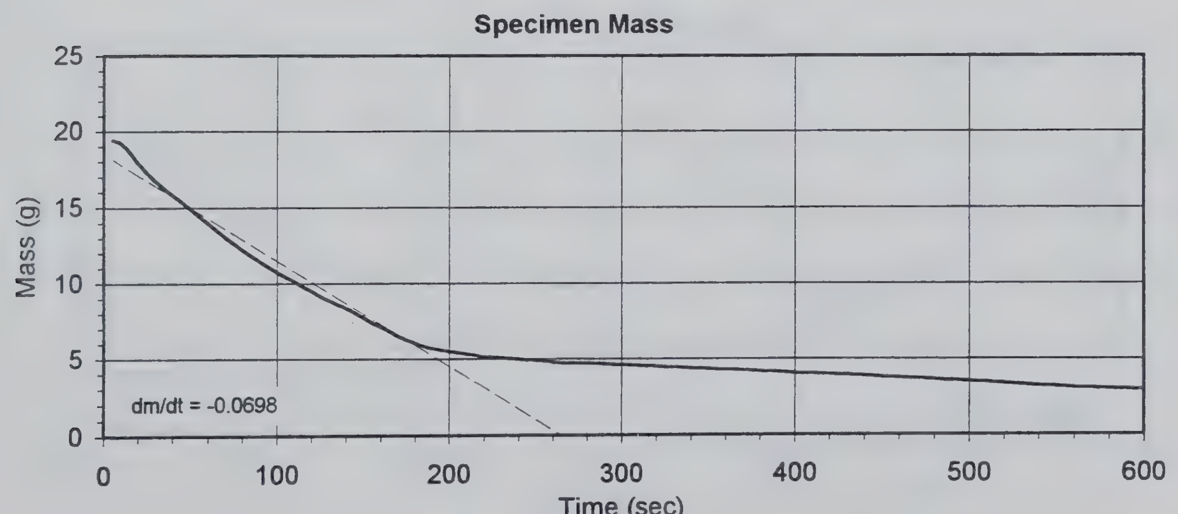




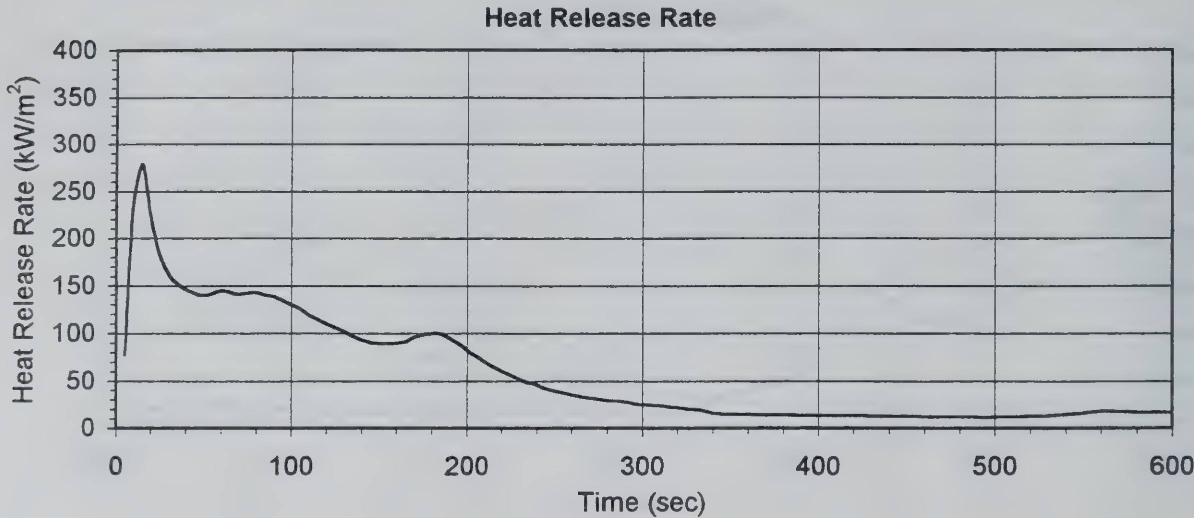
Cone Calorimeter Data R 4.04 Polyurethane with Paper Backing
35 kW/m^2, Test #3

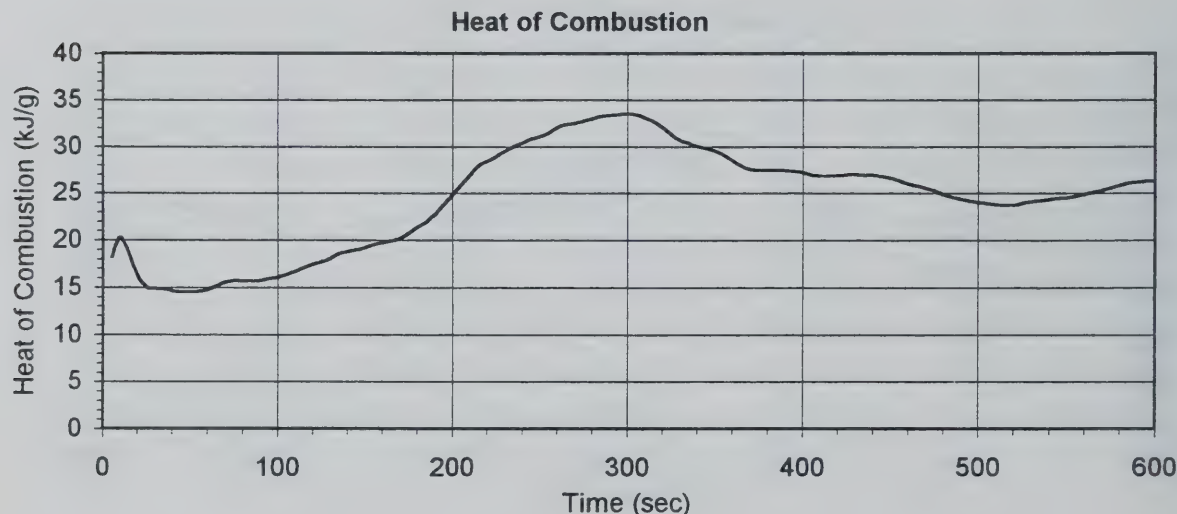


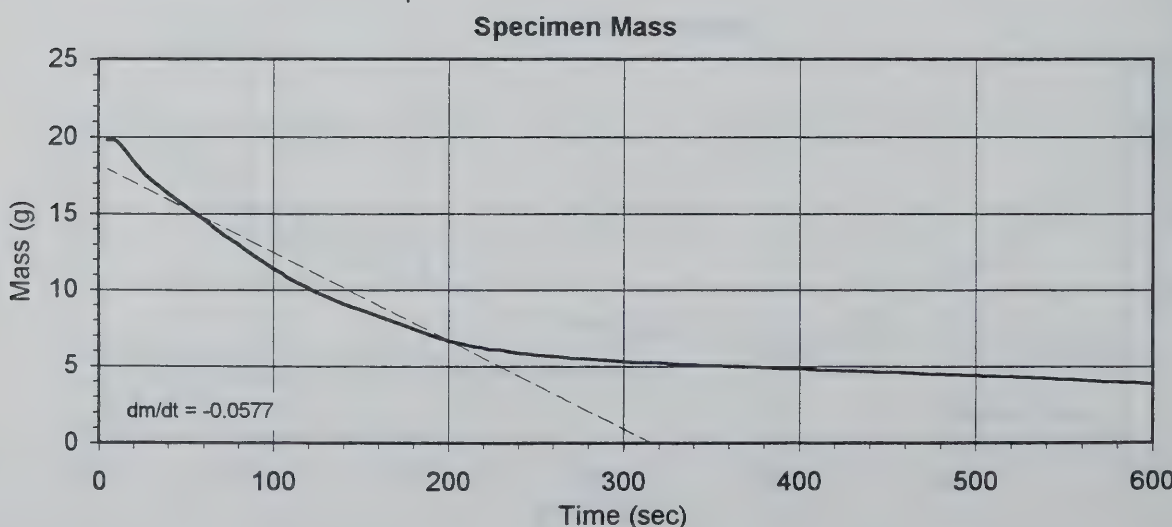




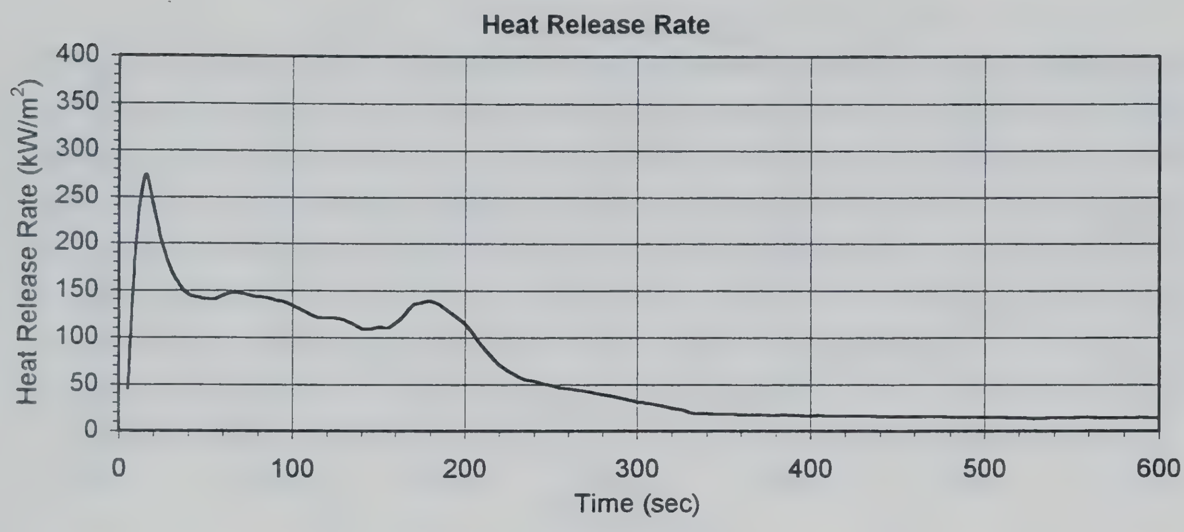
Cone Calorimeter Data R 4.04 Polyurethane with Paper Backing
35 kW/m², Test #4

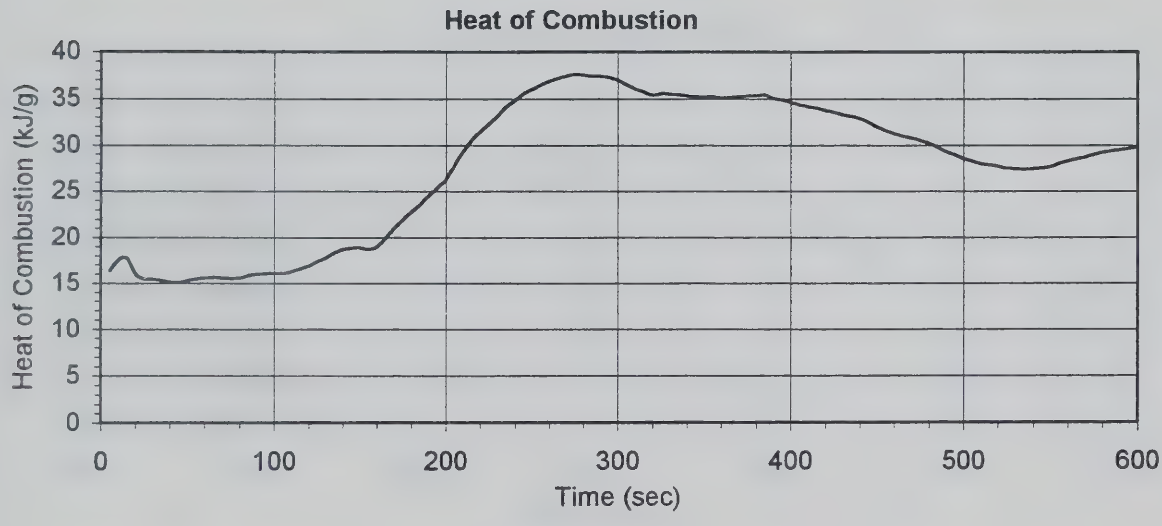


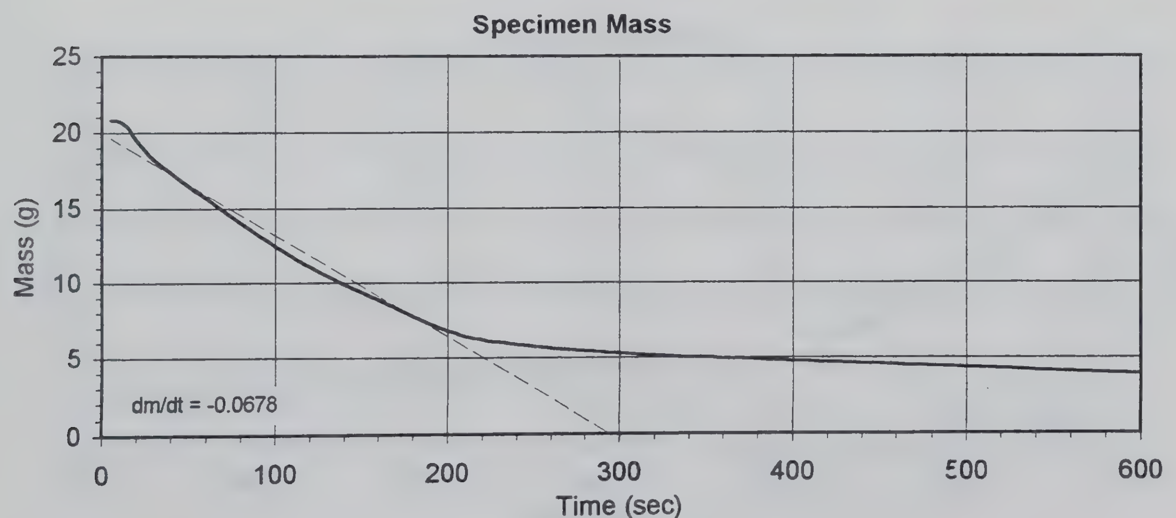




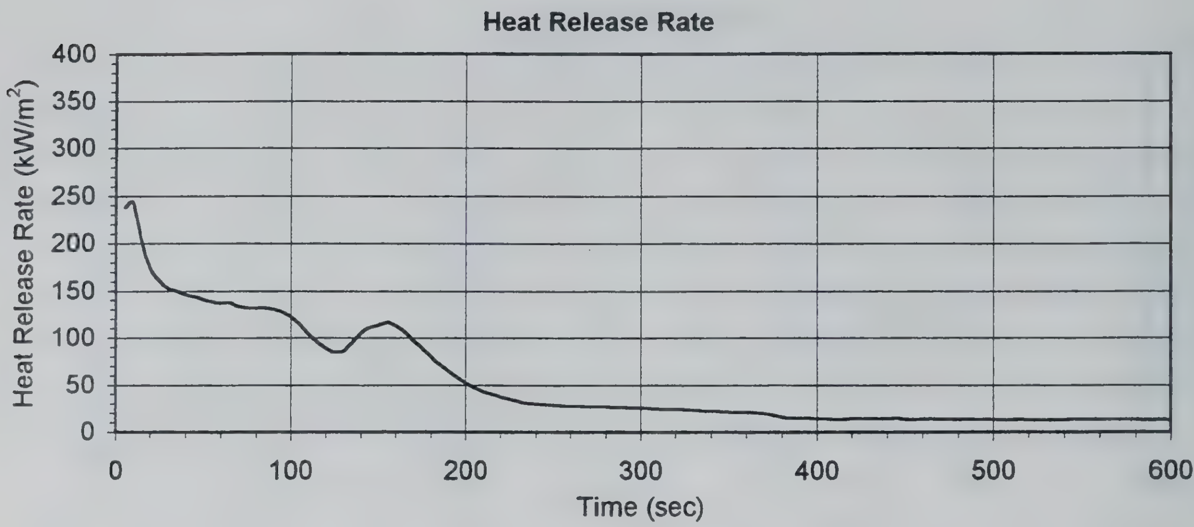
Cone Calorimeter Data R 4.04 Polyurethane with Paper Backing
35 kW/m^2, Test #5

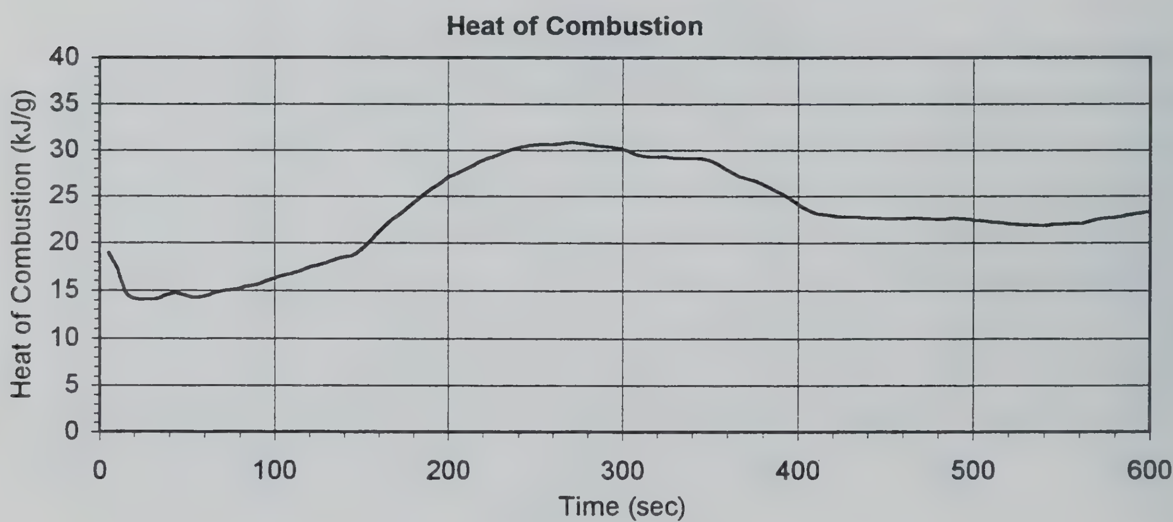


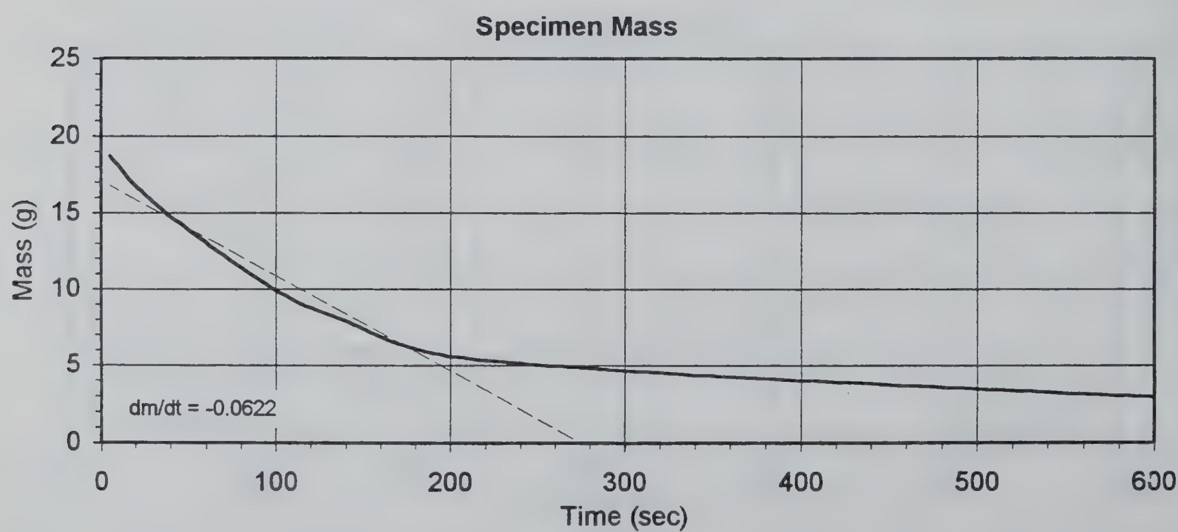




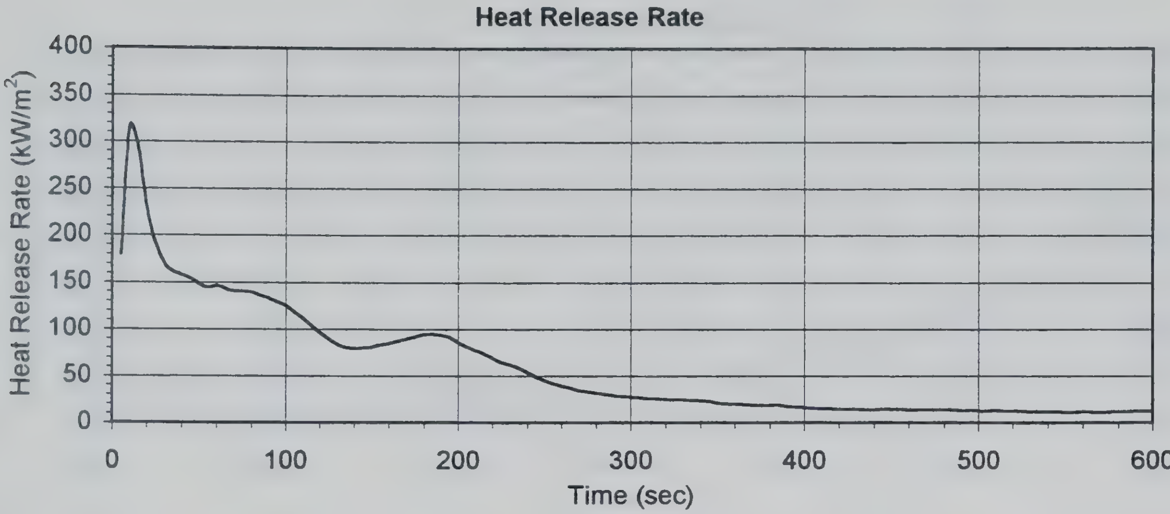
Cone Calorimeter Data R 4.04 Polyurethane with Paper Backing
40 kW/m^2, Test #1

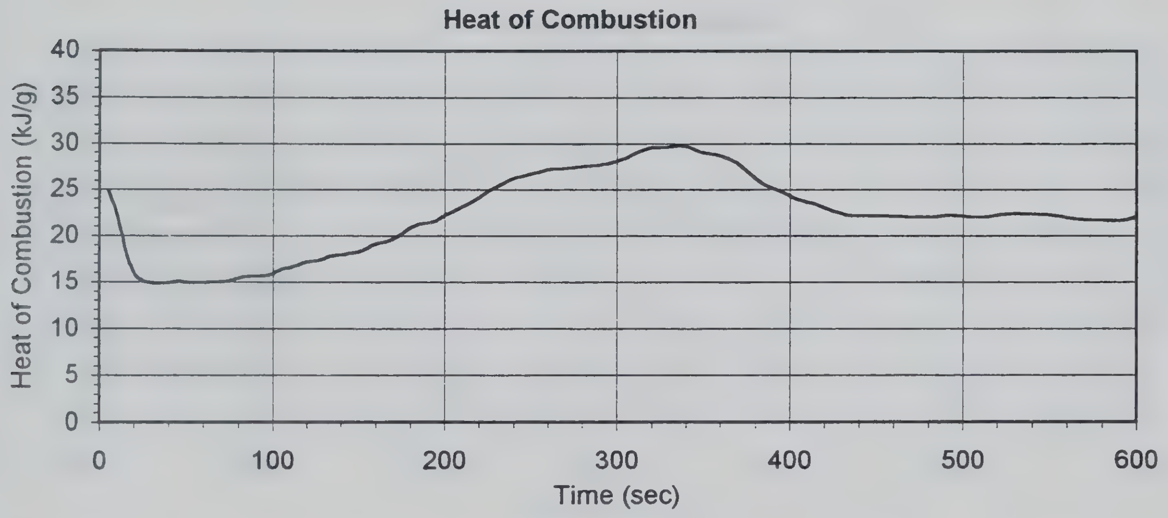


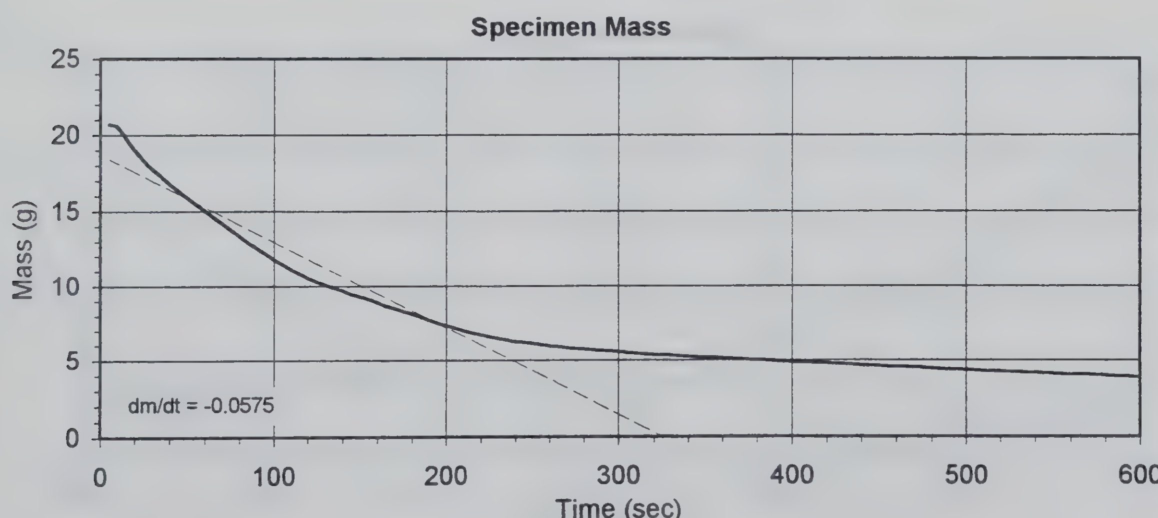




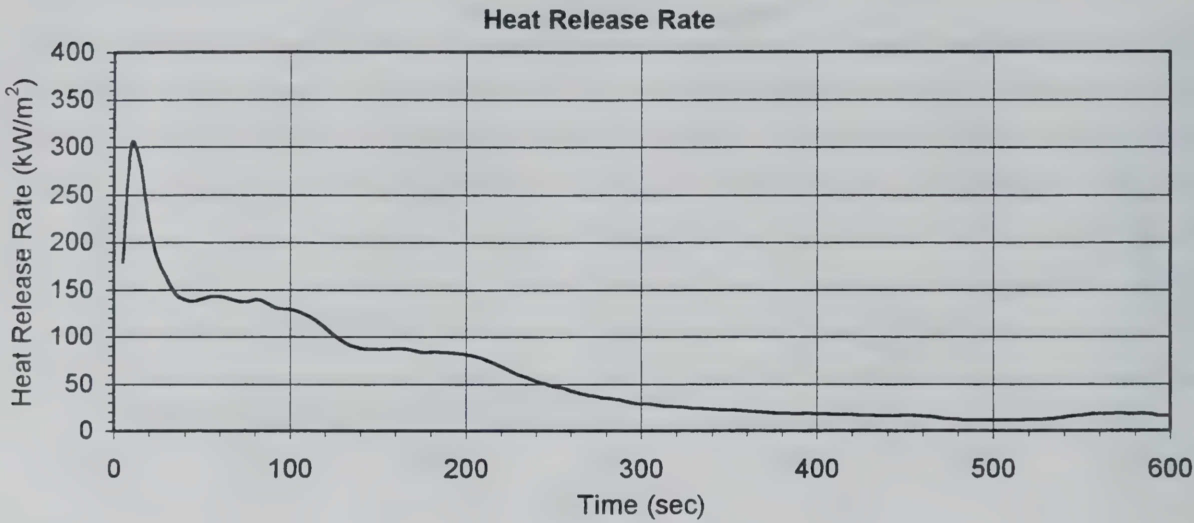
Cone Calorimeter Data R 4.04 Polyurethane with Paper Backing
40 kW/m^2, Test #2

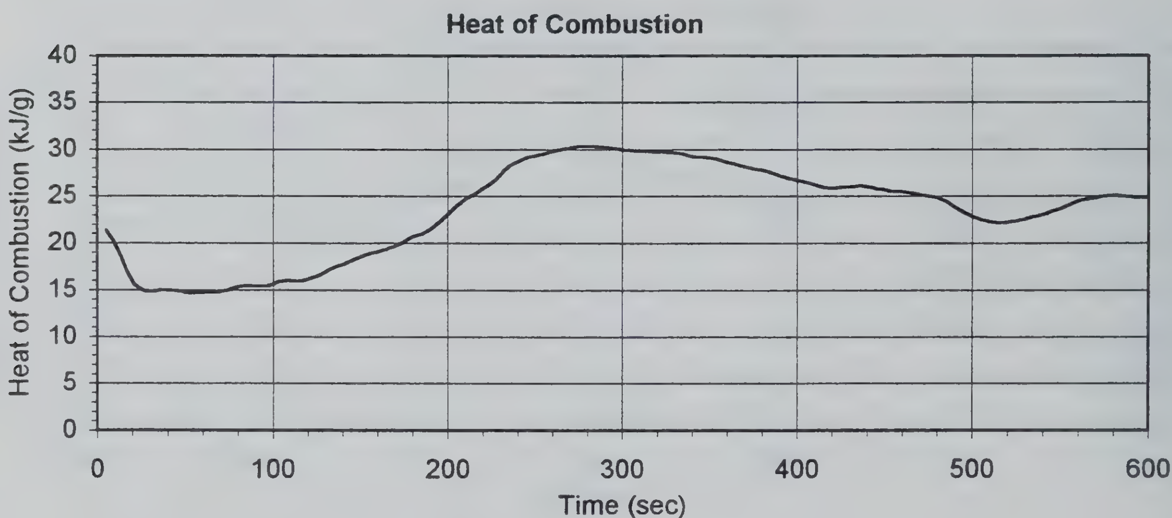


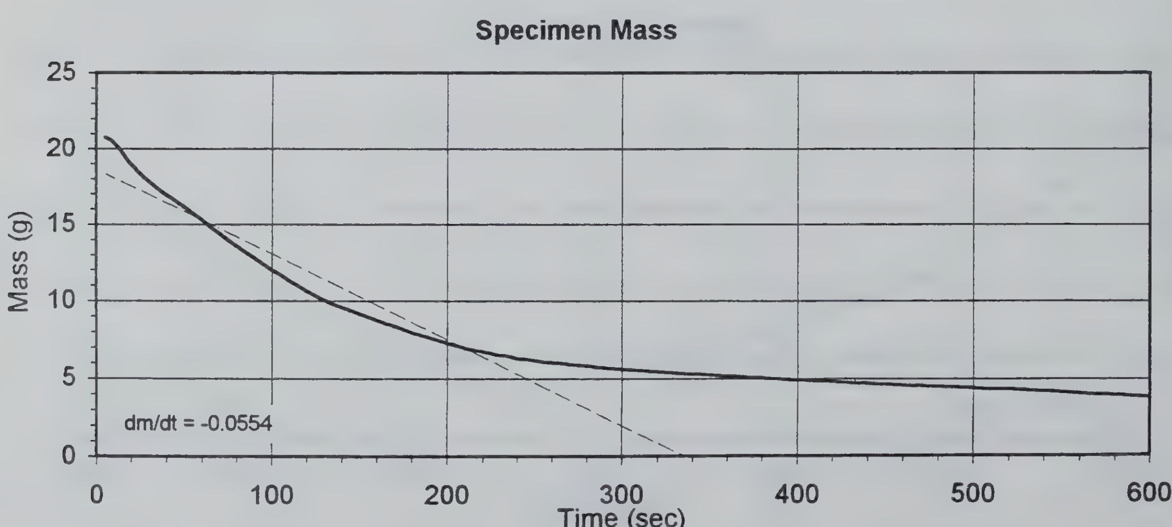




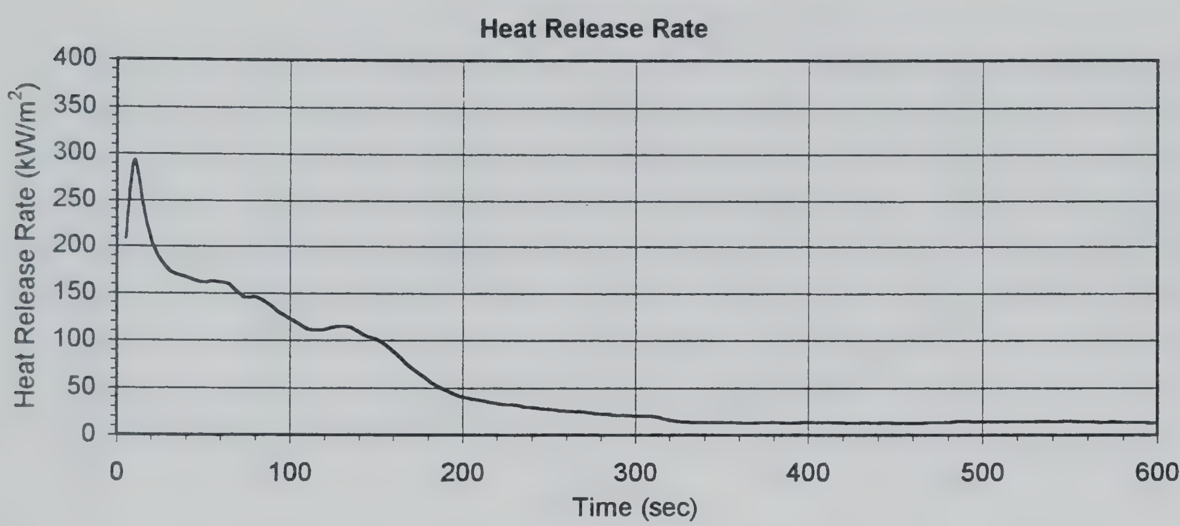
Cone Calorimeter Data R 4.04 Polyurethane with Paper Backing
40 kW/m^2, Test #3

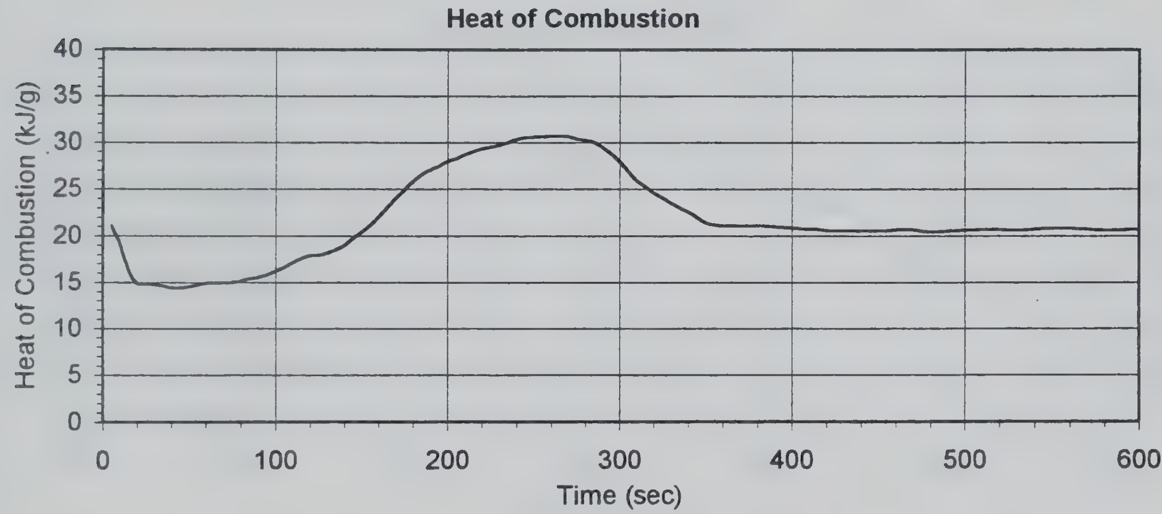


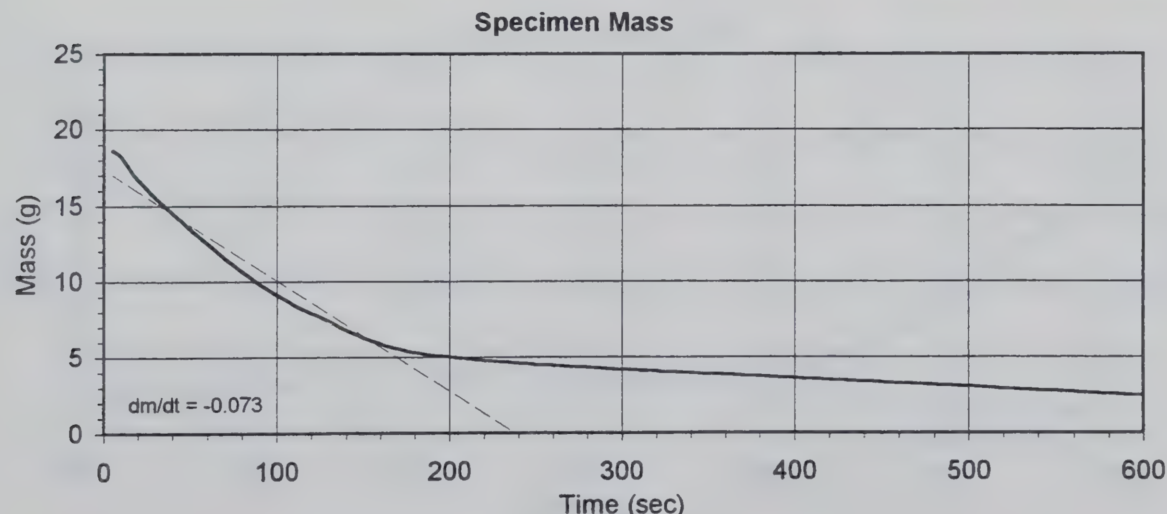




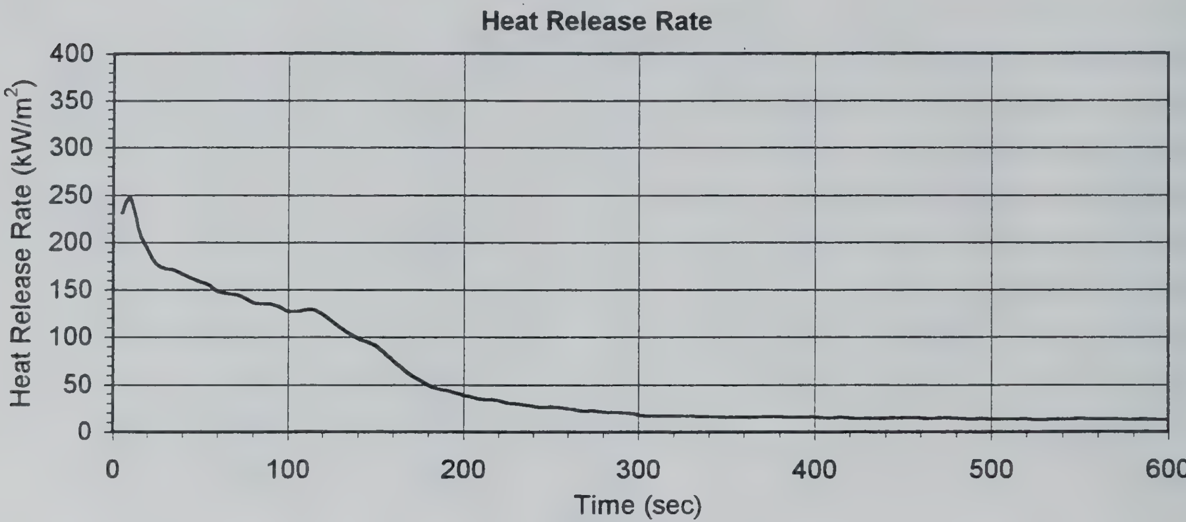
Cone Calorimeter Data R 4.04 Polyurethane with Paper Backing
40 kW/m^2, Test #4

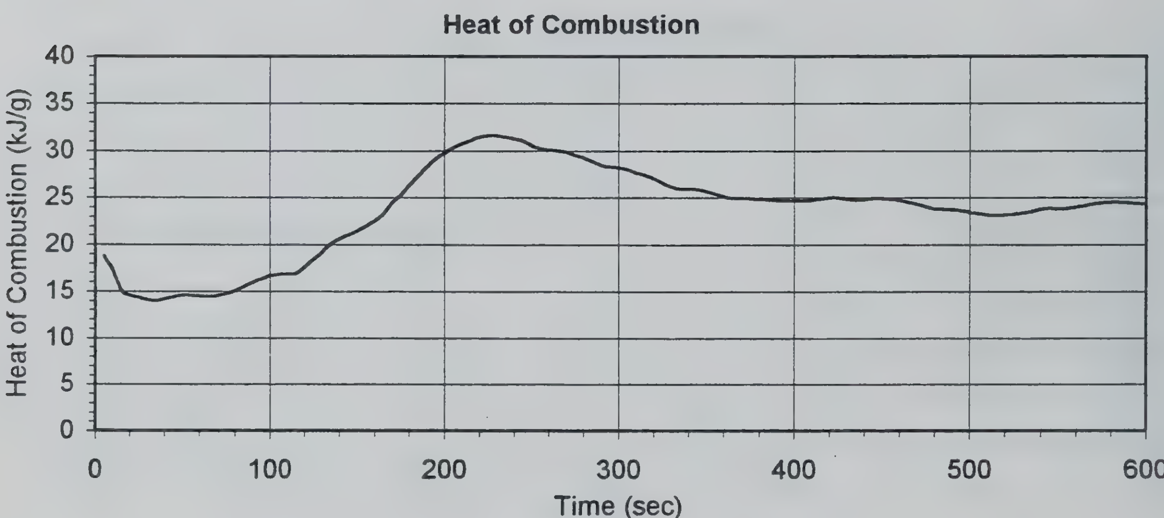


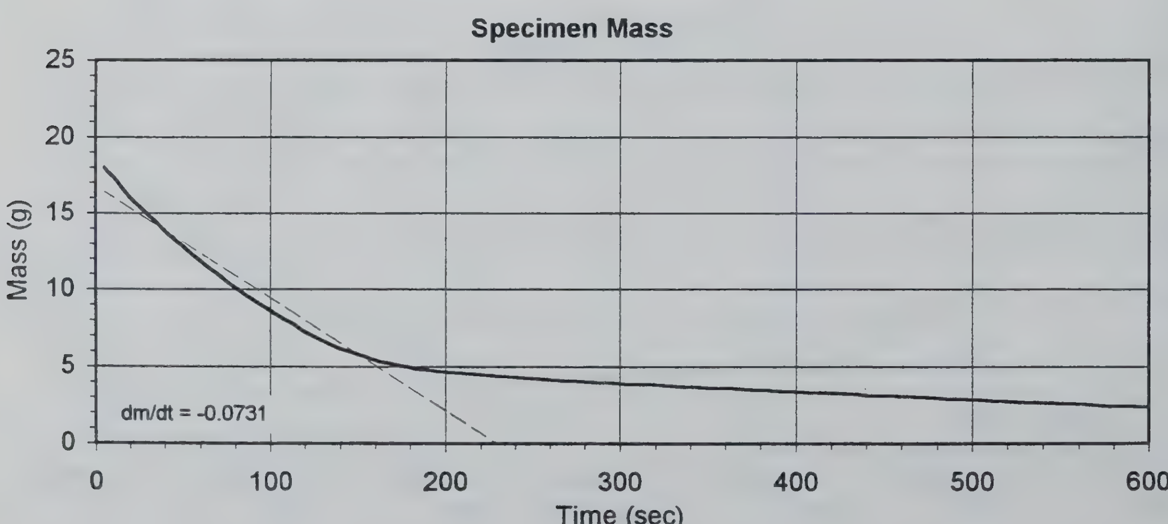




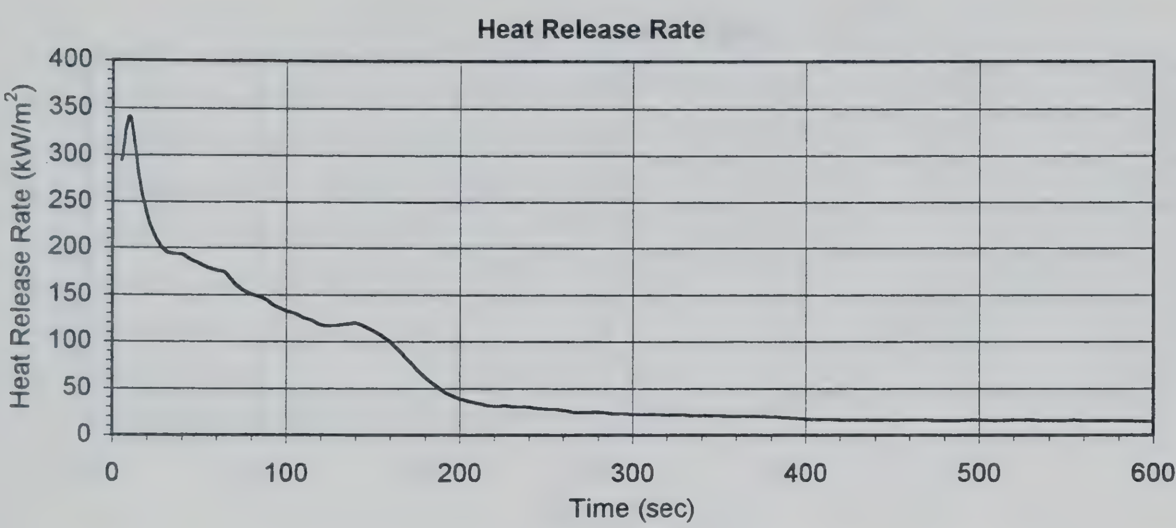
Cone Calorimeter Data R 4.04 Polyurethane with Paper Backing
40 kW/m^2, Test #5

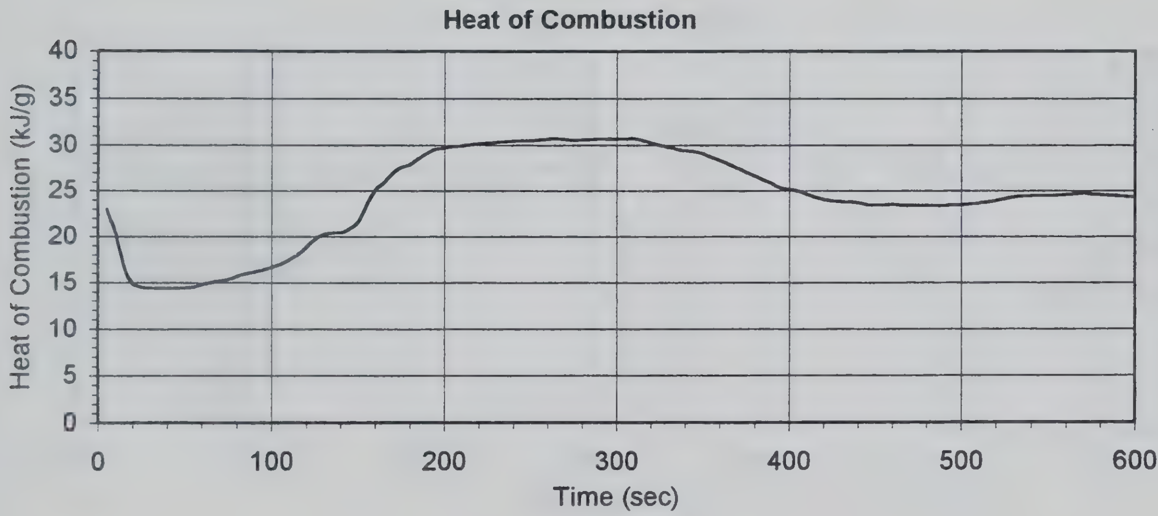


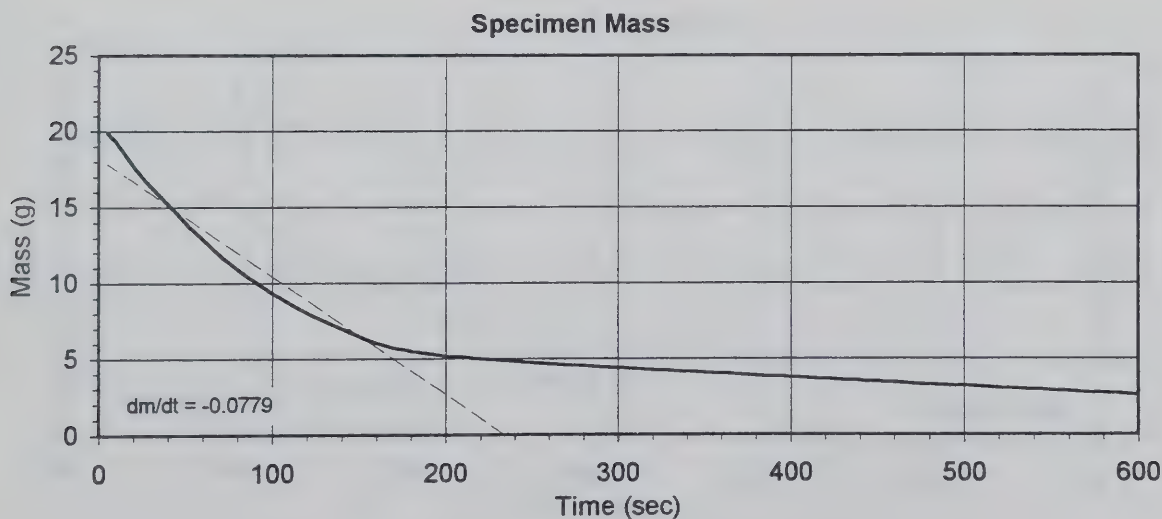




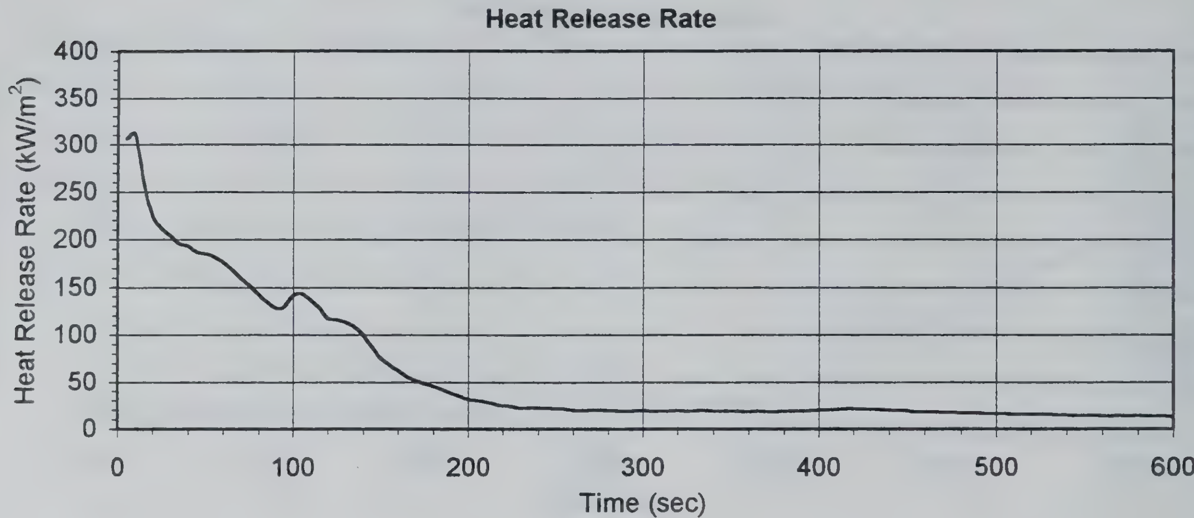
Cone Calorimeter Data R 4.04 Polyurethane with Paper Backing
50 kW/m^2, Test #1

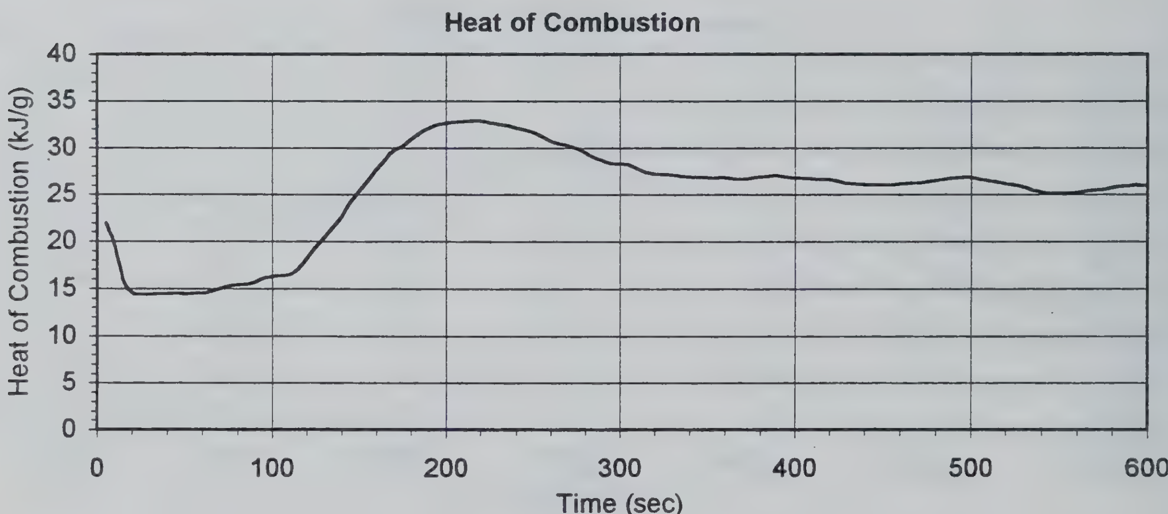


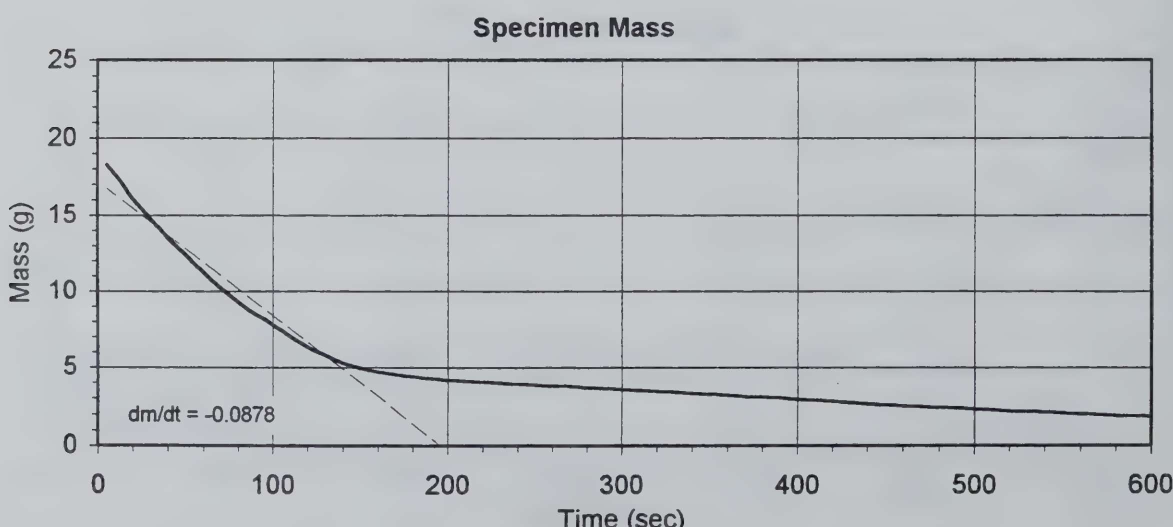




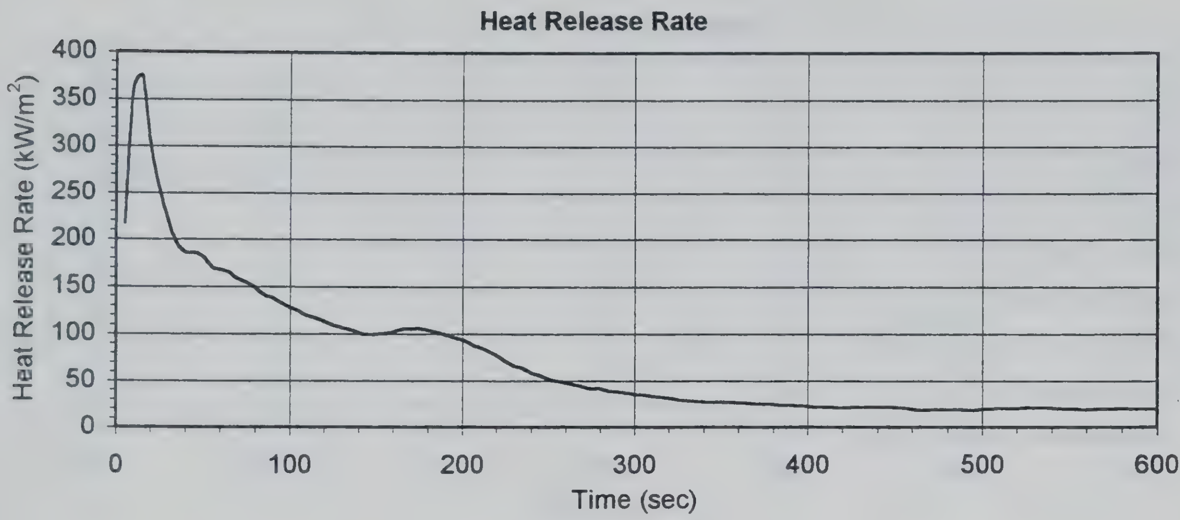
Cone Calorimeter Data R 4.04 Polyurethane with Paper Backing
50 kW/m², Test #2

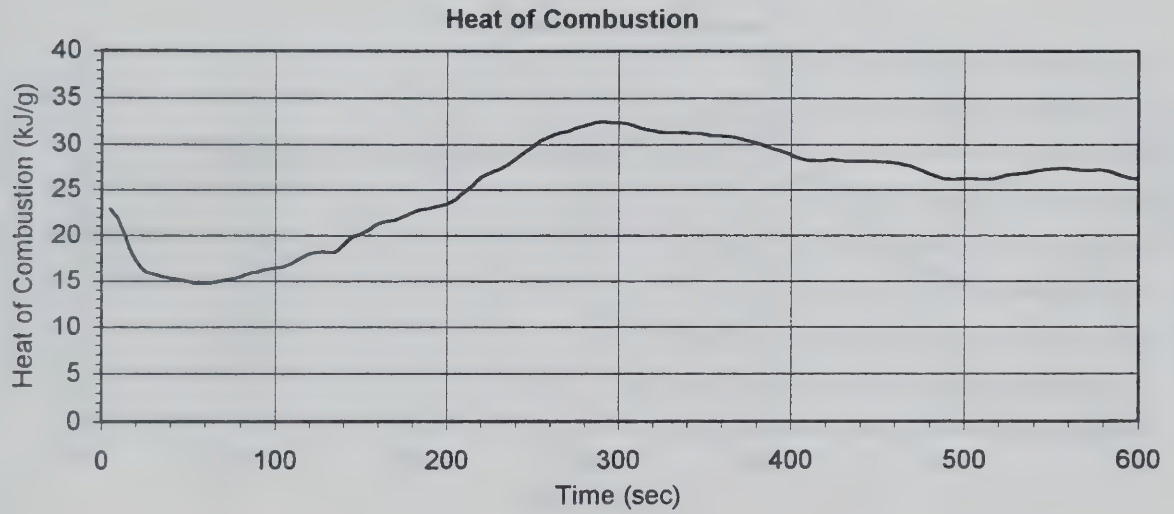


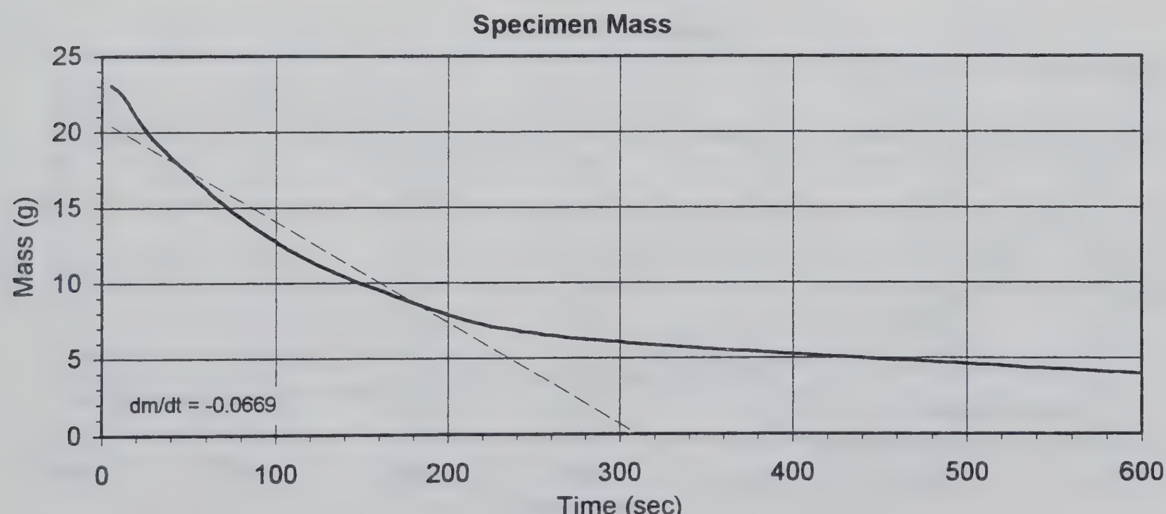




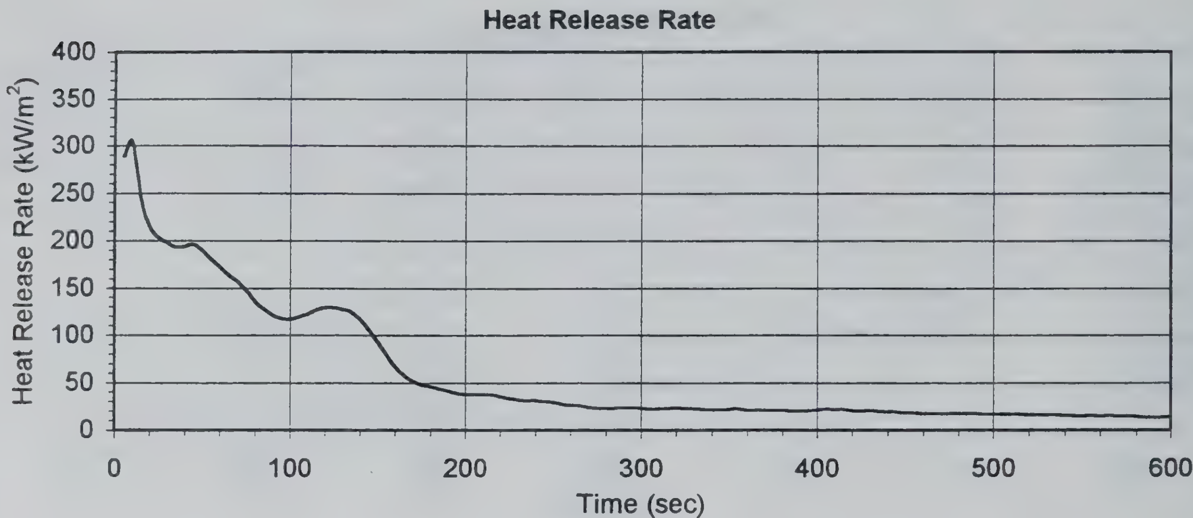
Cone Calorimeter Data R 4.04 Polyurethane with Paper Backing
50 kW/m^2, Test #3

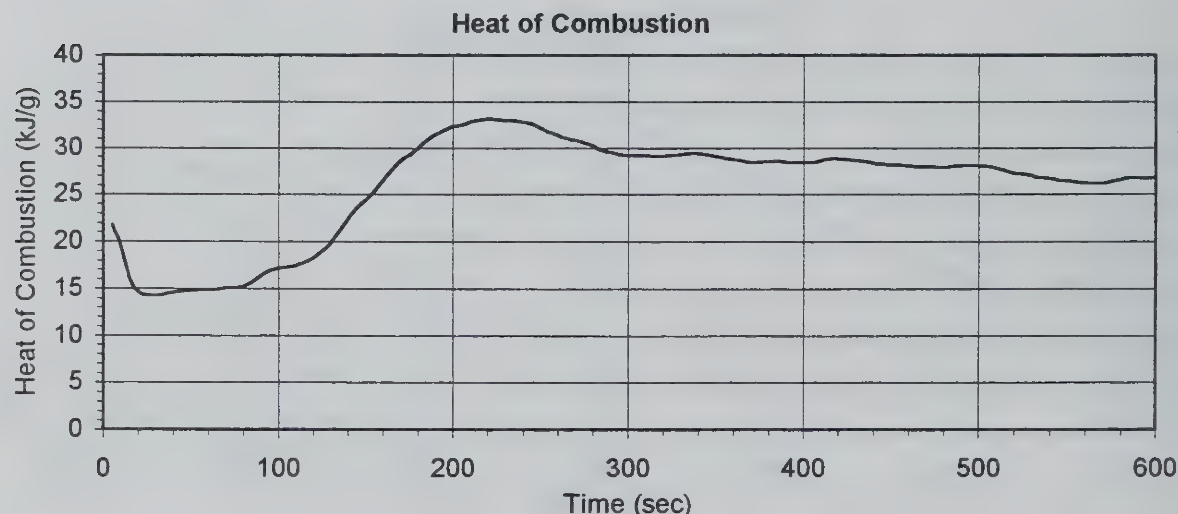


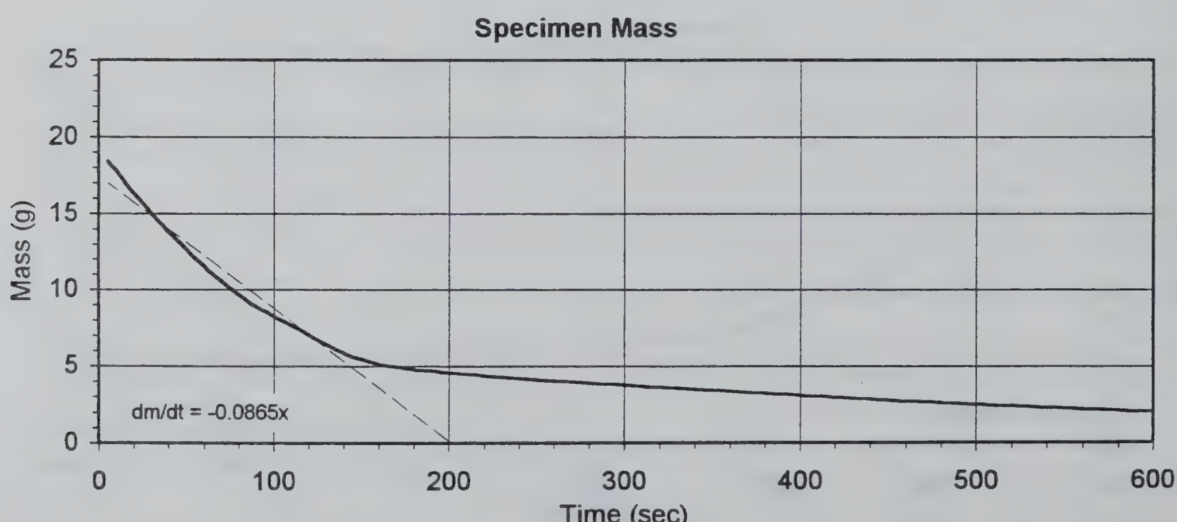




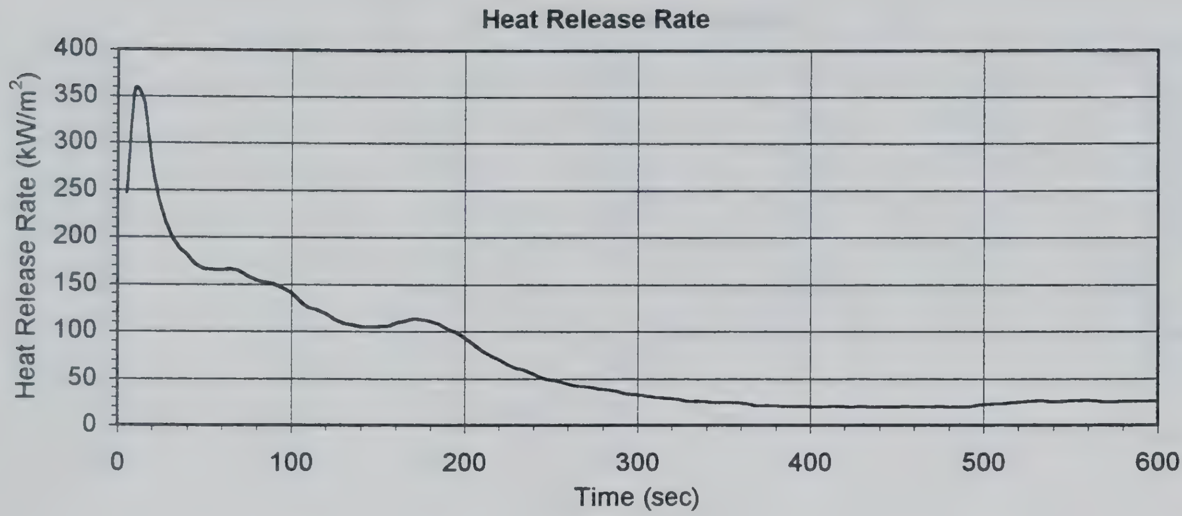
Cone Calorimeter Data R 4.04 Polyurethane with Paper Backing
50 kW/m², Test #4

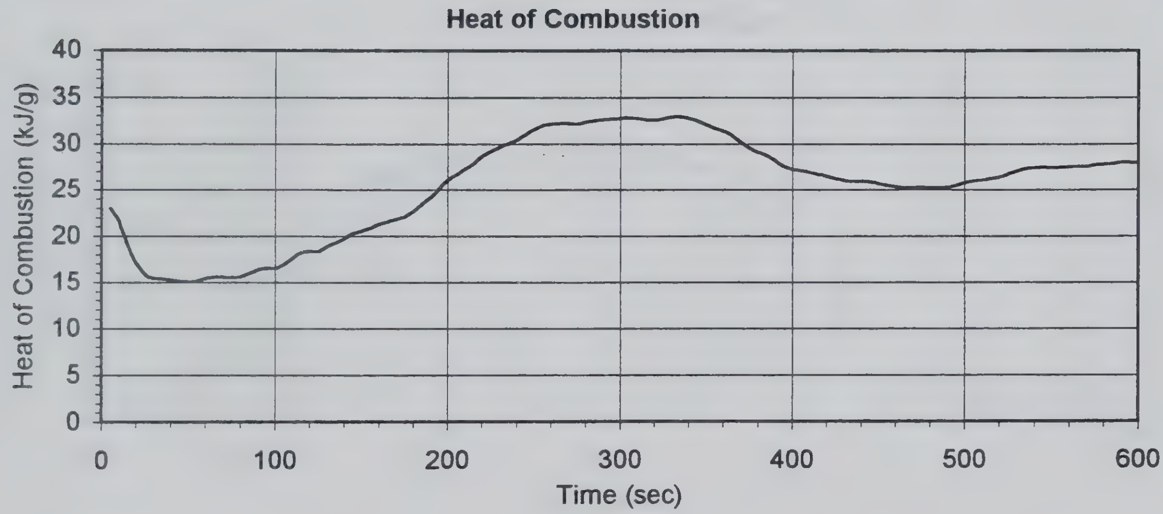


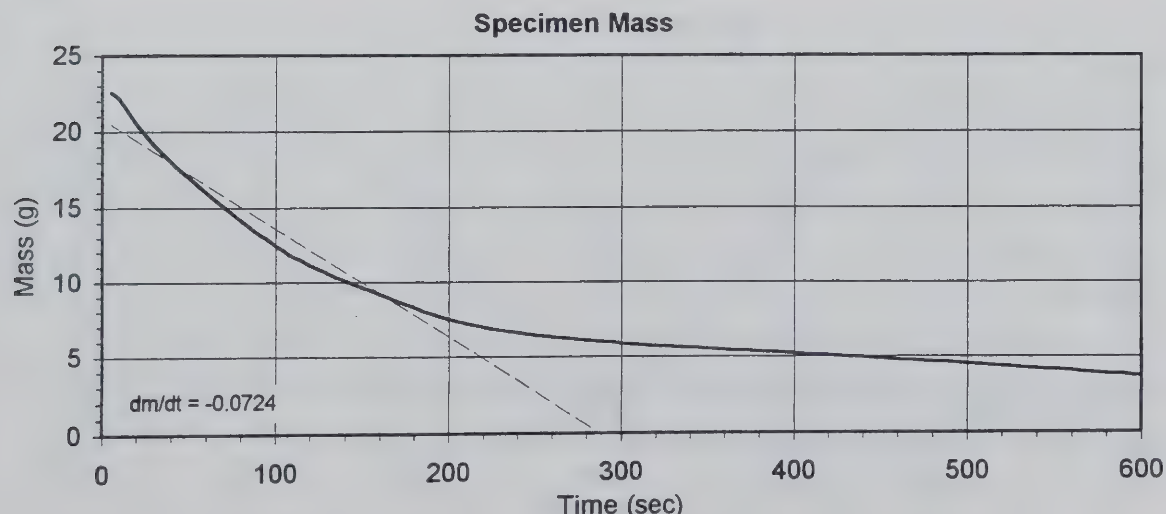




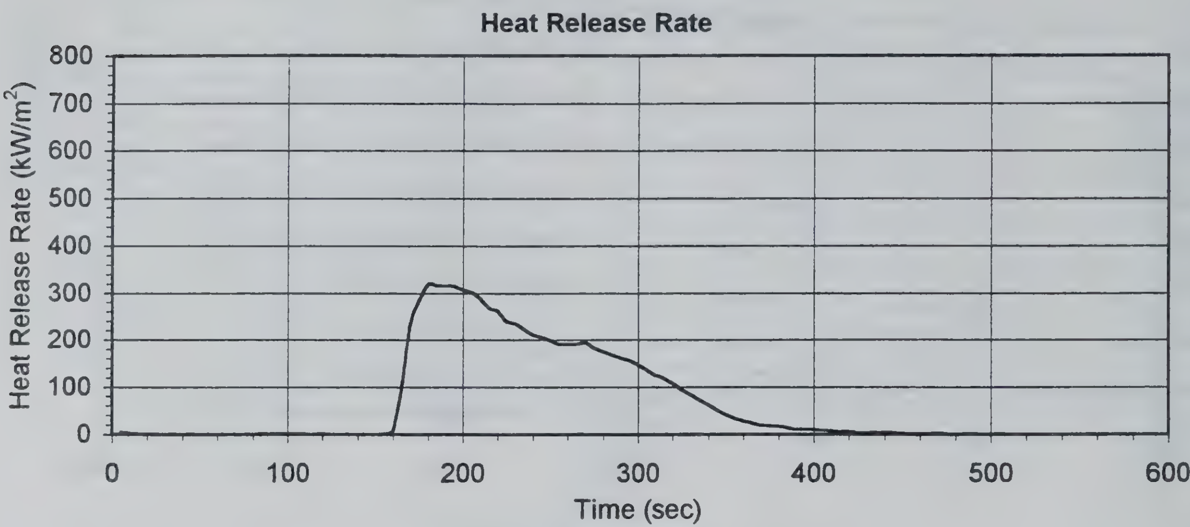
Cone Calorimeter Data R 4.04 Polyurethane with Paper Backing
50 kW/m^2, Test #5

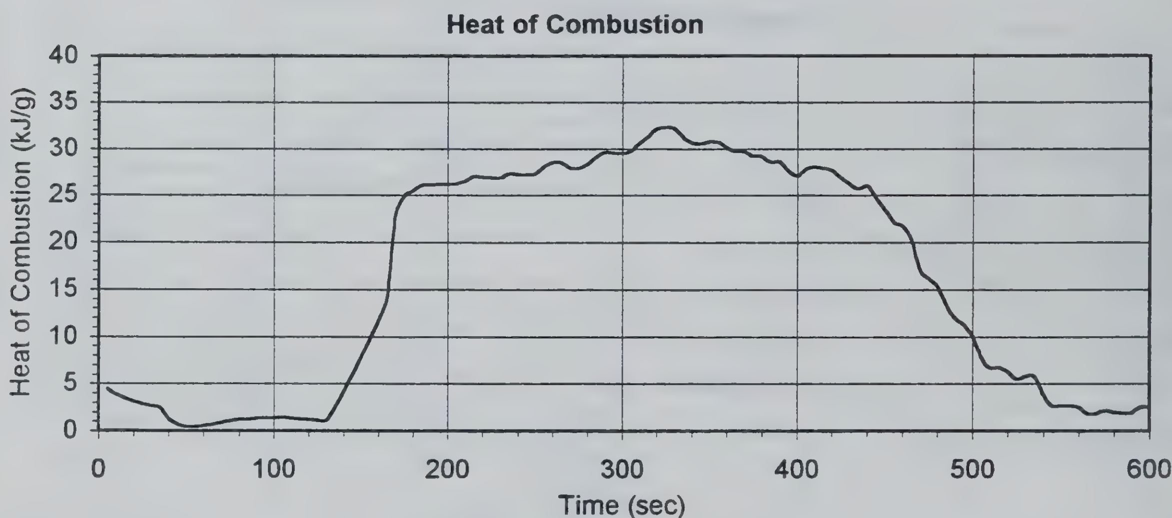


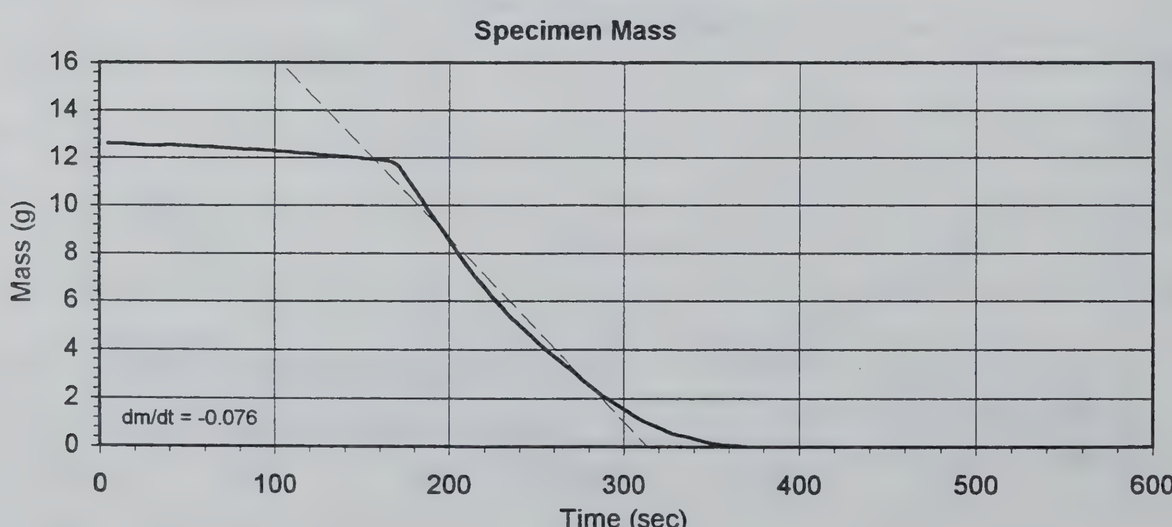




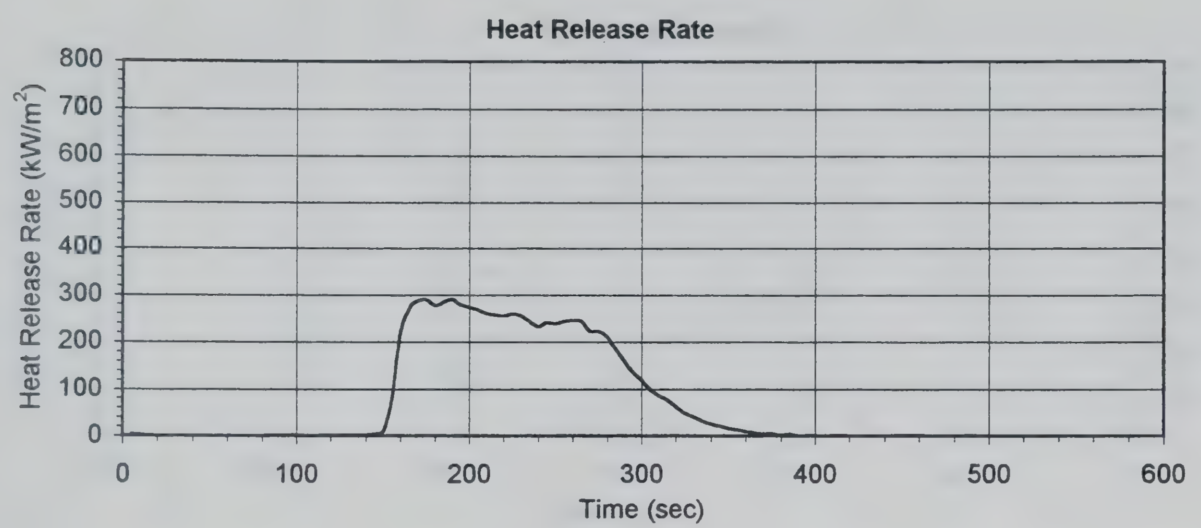
Cone Calorimeter Data R 4.05 F.R. Extruded Polystyrene Board (40 mm)
25 kW/m^2, Test #1

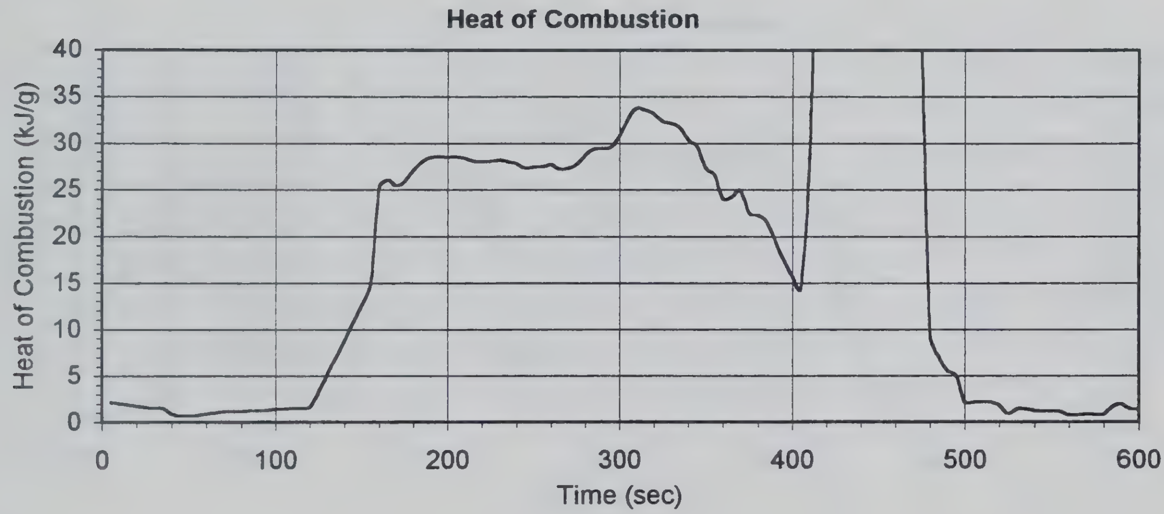


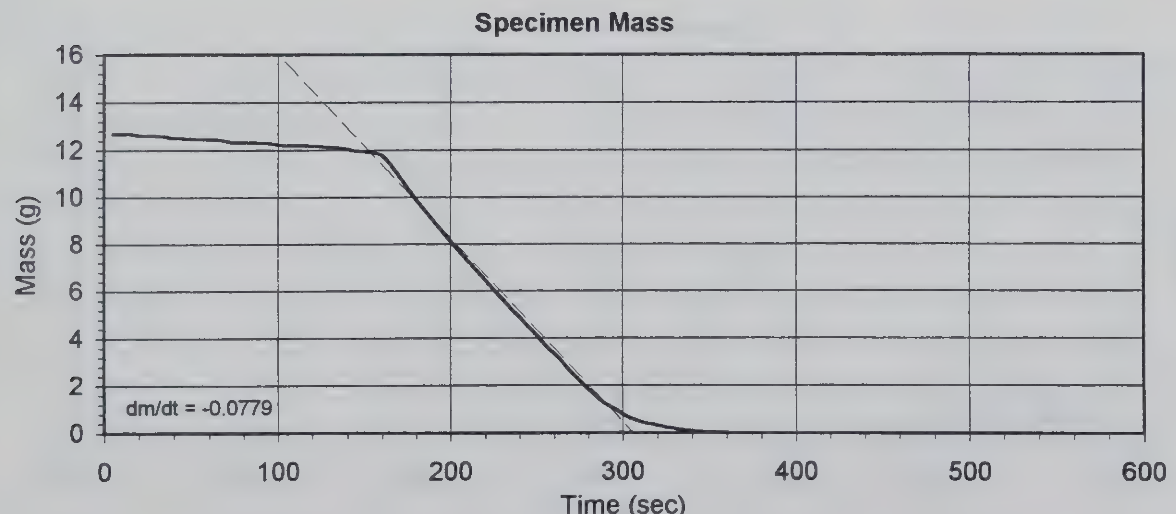




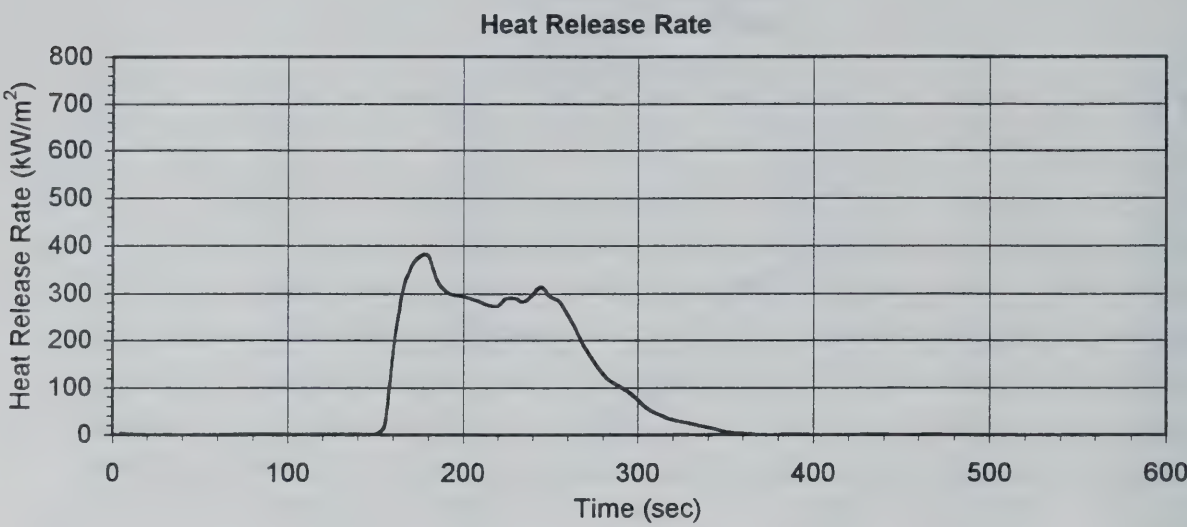
Cone Calorimeter Data R 4.05 F.R. Extruded Polystyrene Board (40 mm)
25 kW/m^2, Test #2

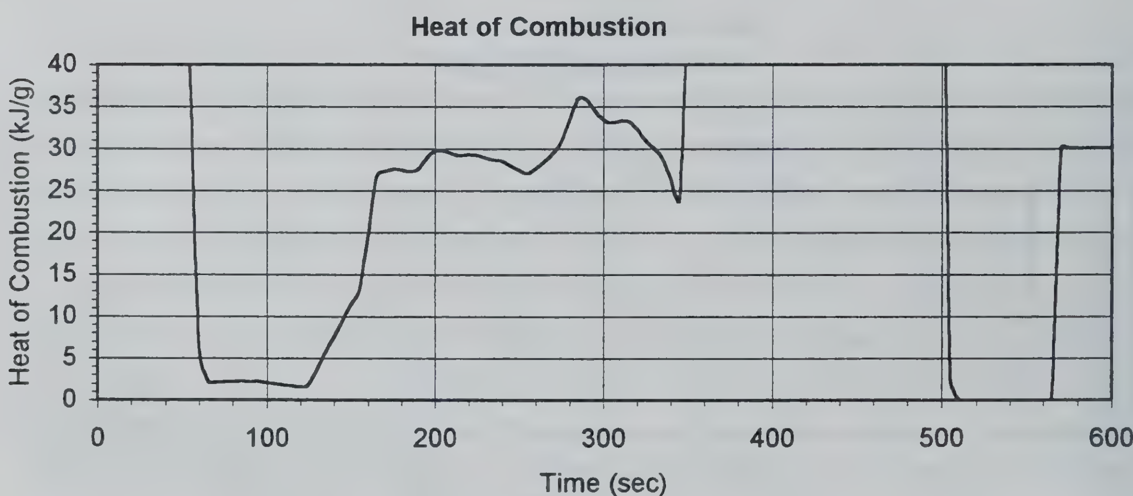


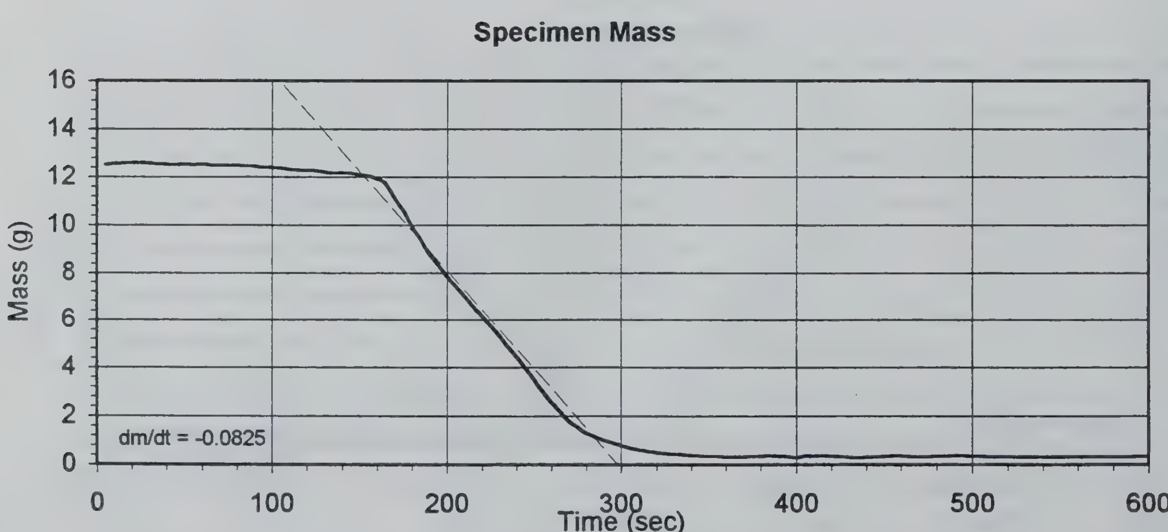




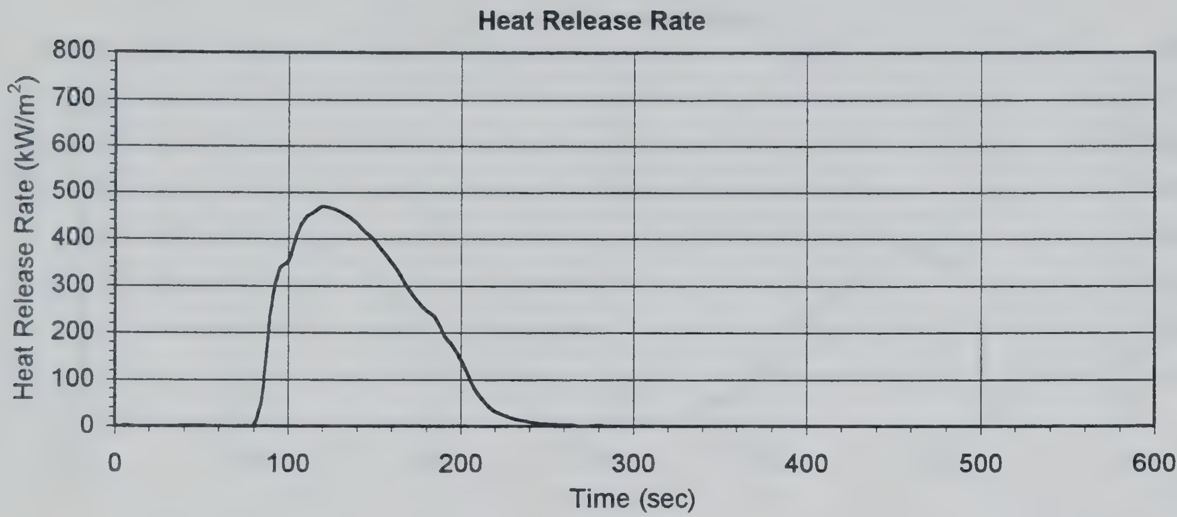
Cone Calorimeter Data R 4.05 F.R. Extruded Polystyrene Board (40 mm)
25 kW/m^2, Test #5

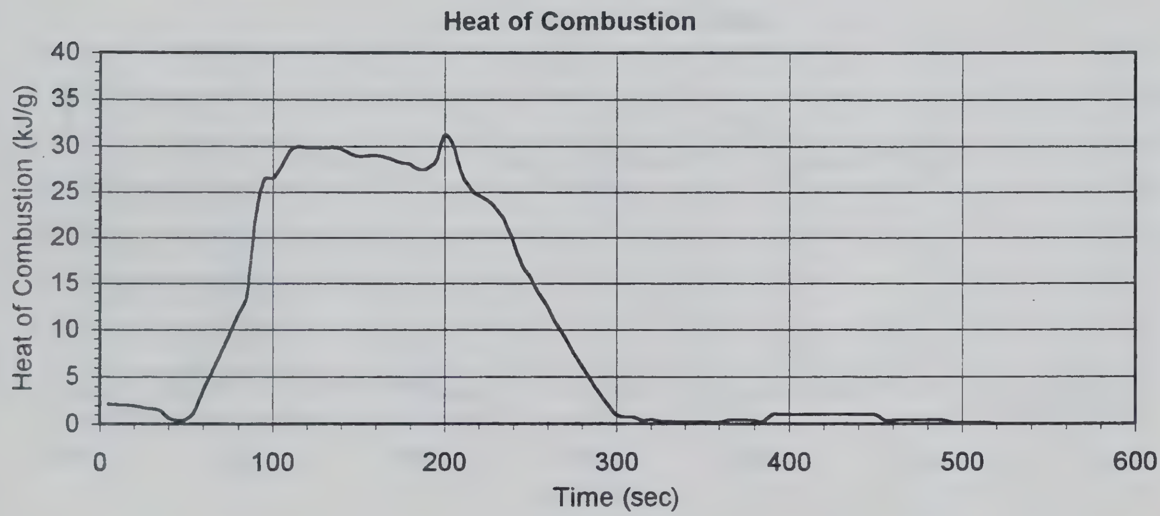


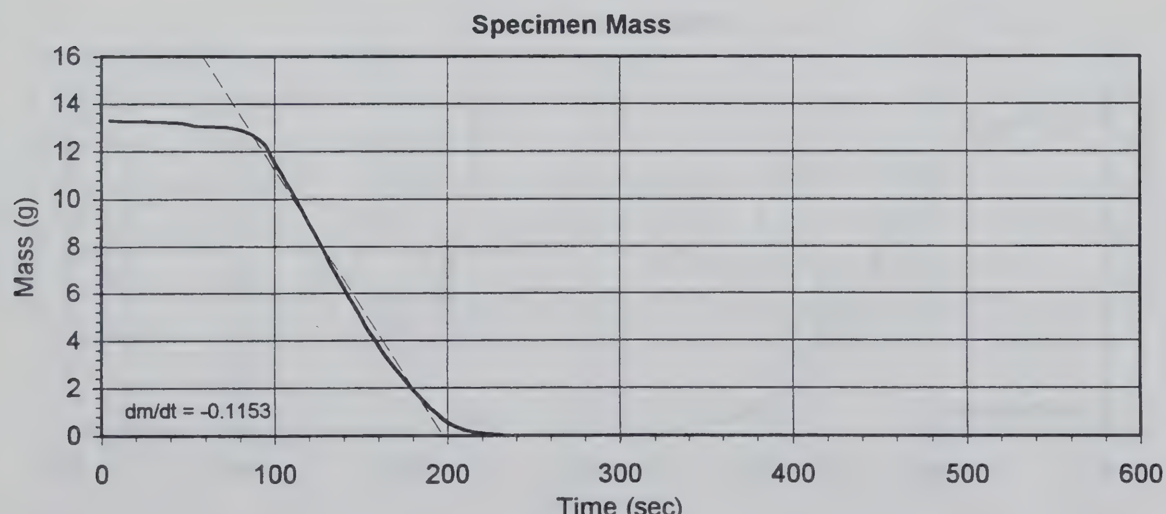




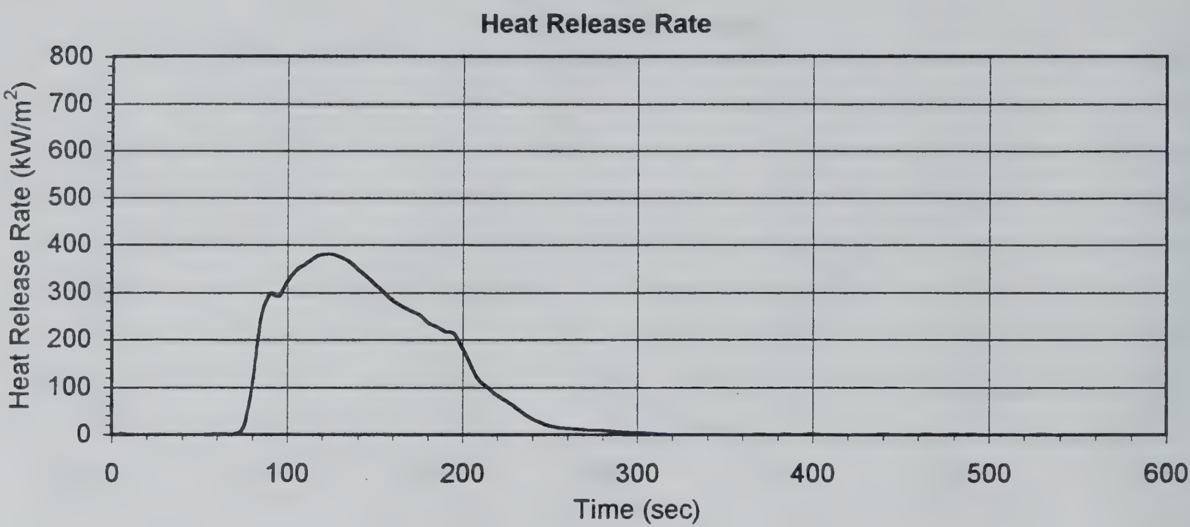
Cone Calorimeter Data R 4.05 F.R. Extruded Polystyrene Board (40 mm)
35 kW/m^2, Test #1

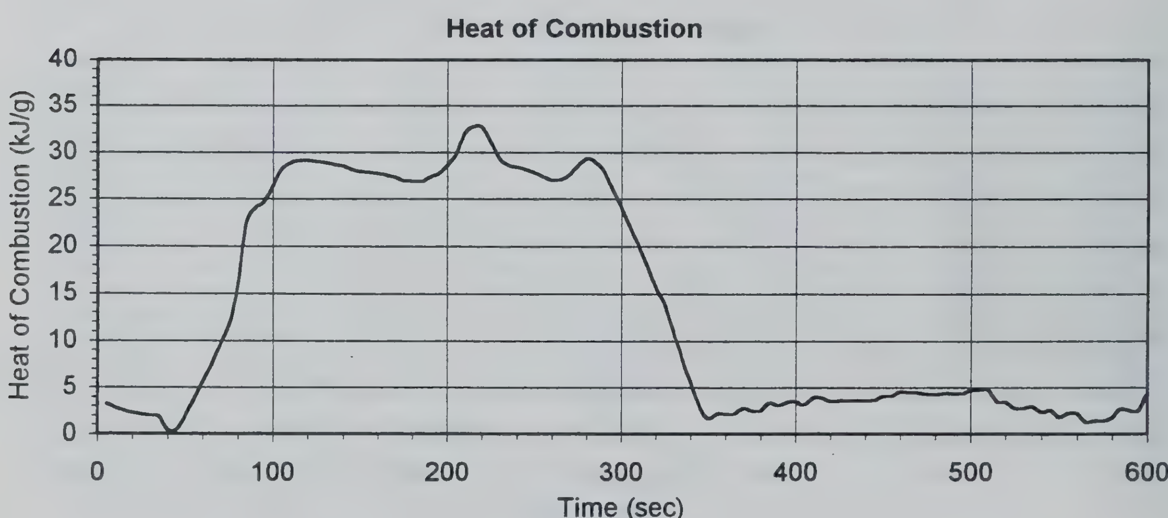


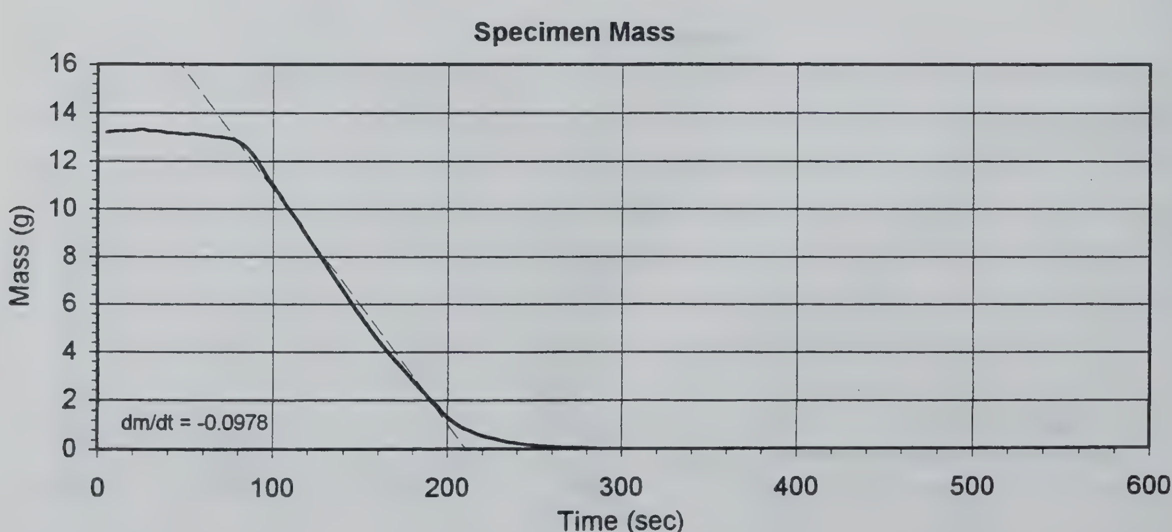




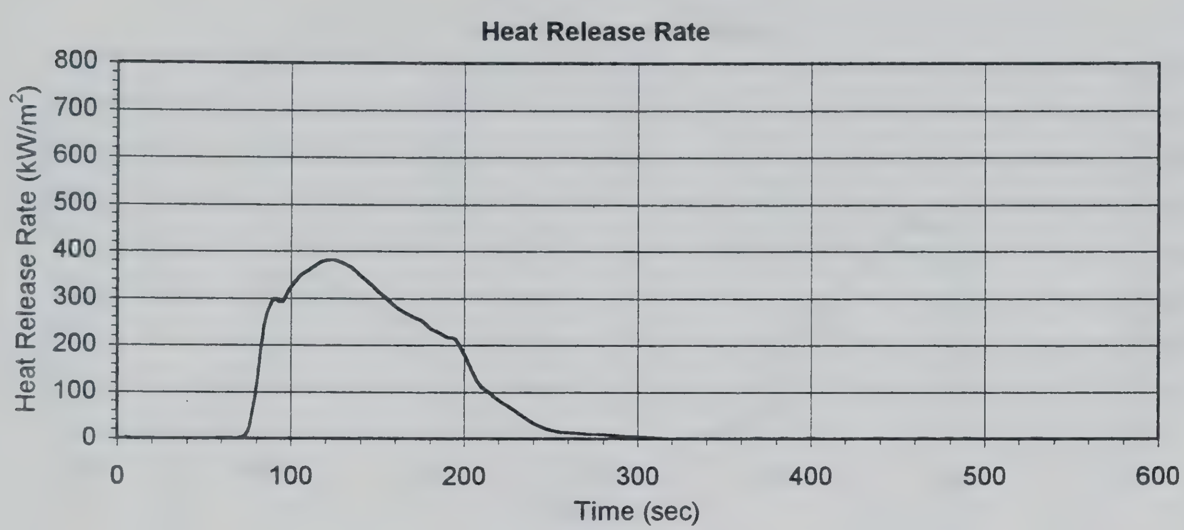
Cone Calorimeter Data R 4.05 F.R. Extruded Polystyrene Board (40 mm)
35 kW/m², Test #2

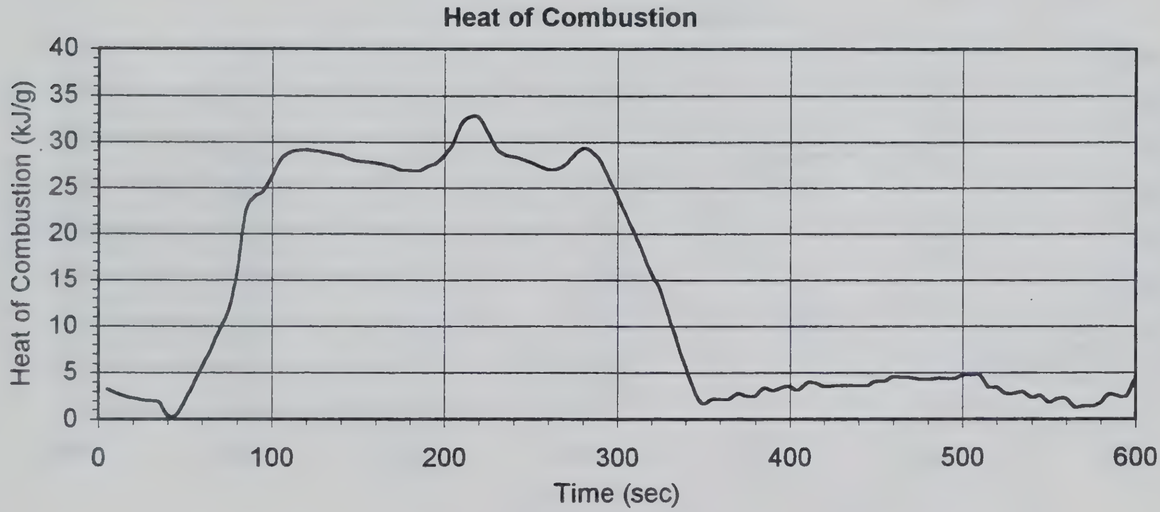


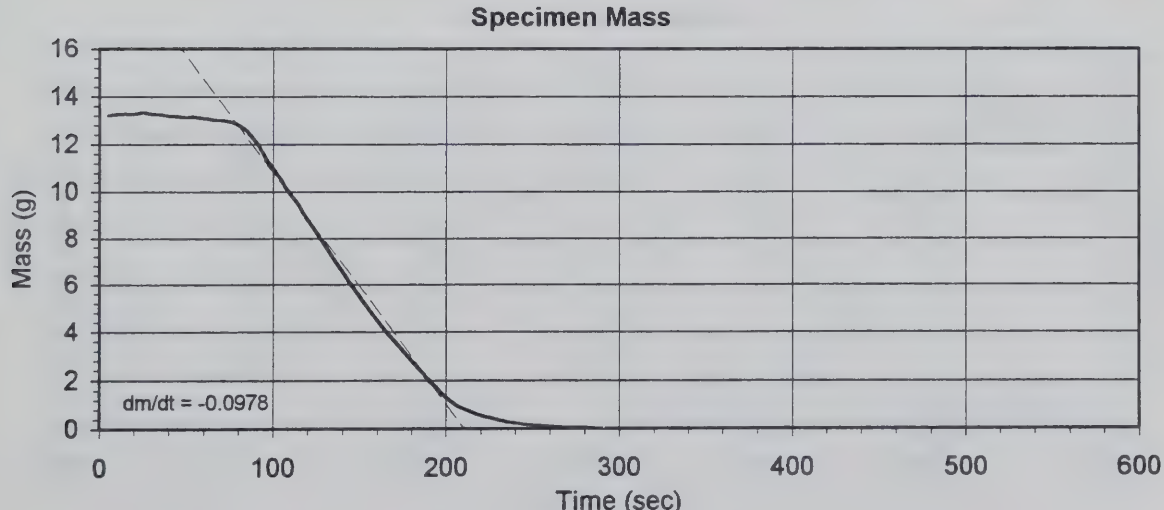




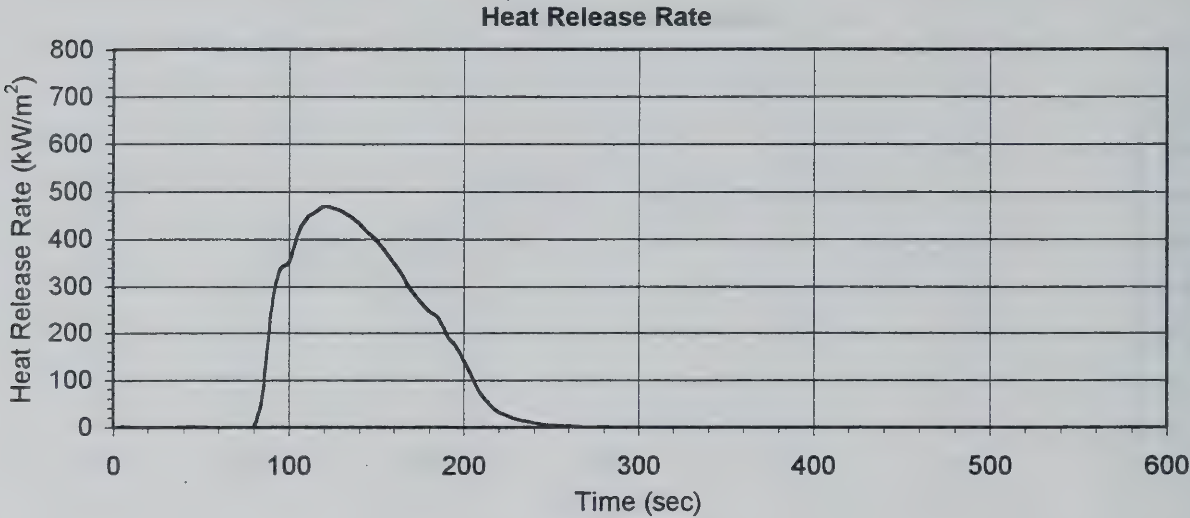
Cone Calorimeter Data R 4.05 F.R. Extruded Polystyrene Board (40 mm)
35 kW/m^2, Test #2

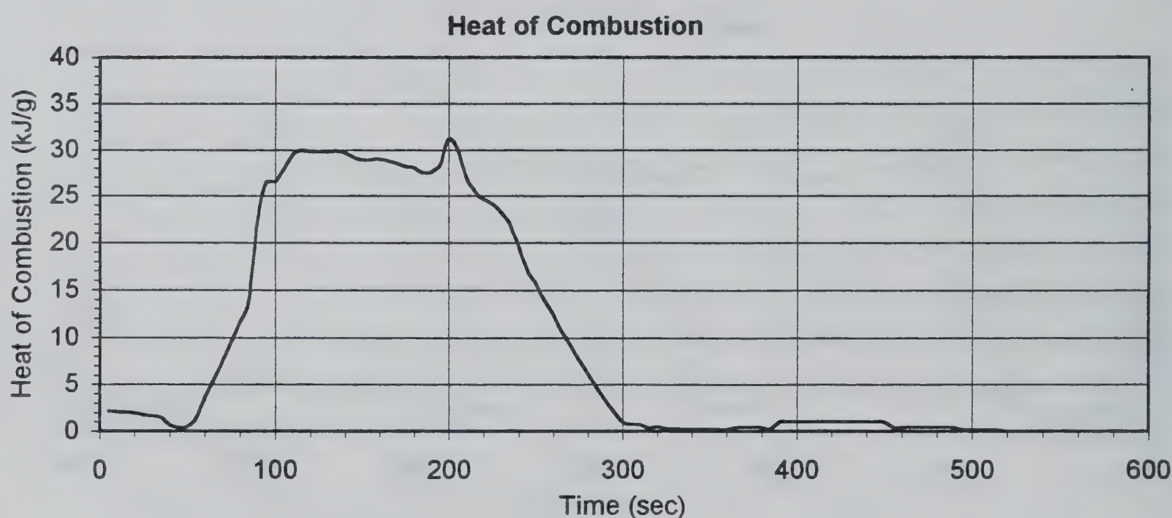


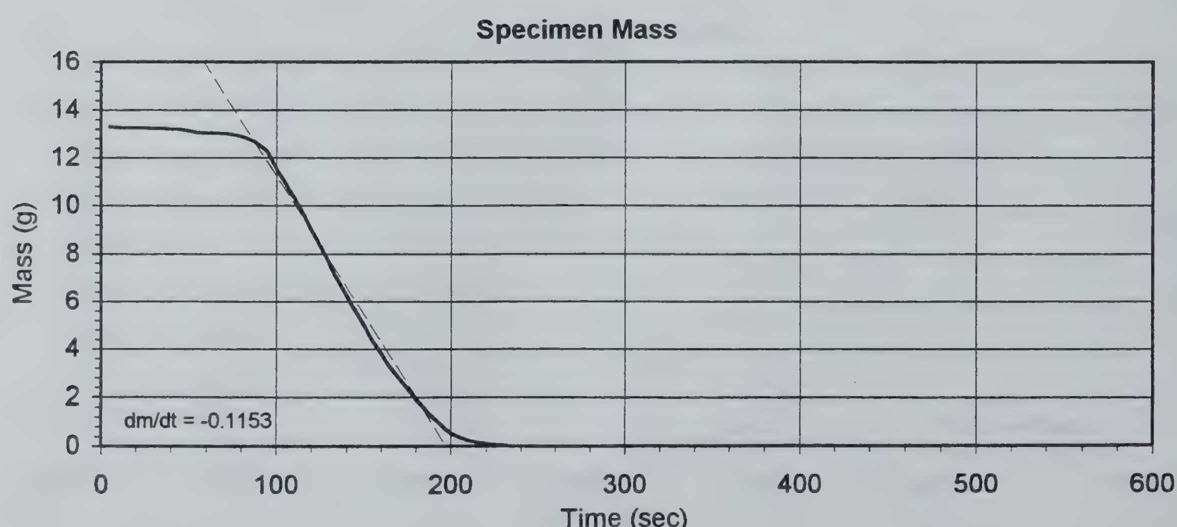




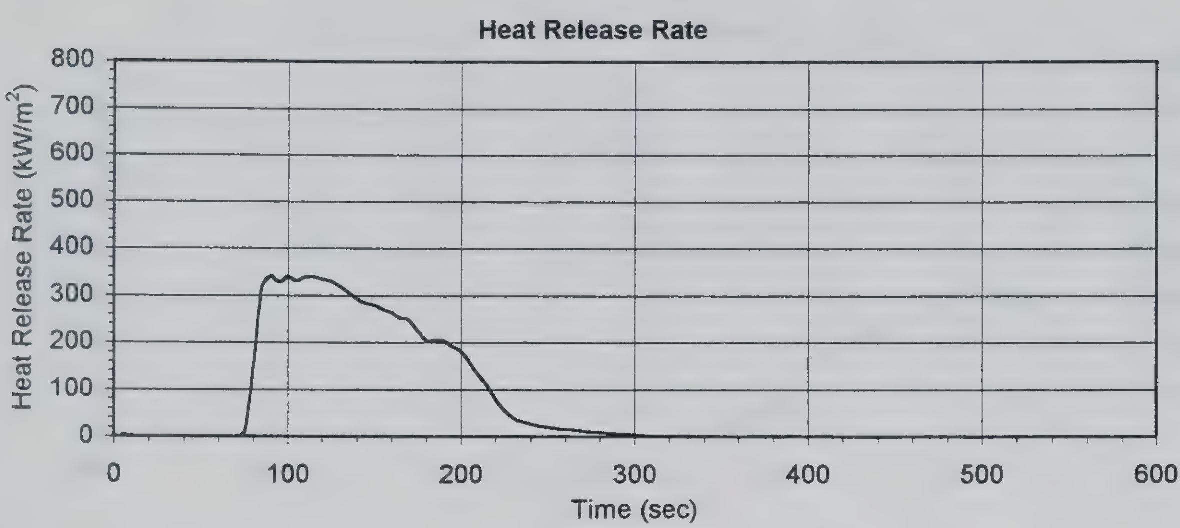
Cone Calorimeter Data R 4.05 F.R. Extruded Polystyrene Board (40 mm)
35 kW/m², Test #1

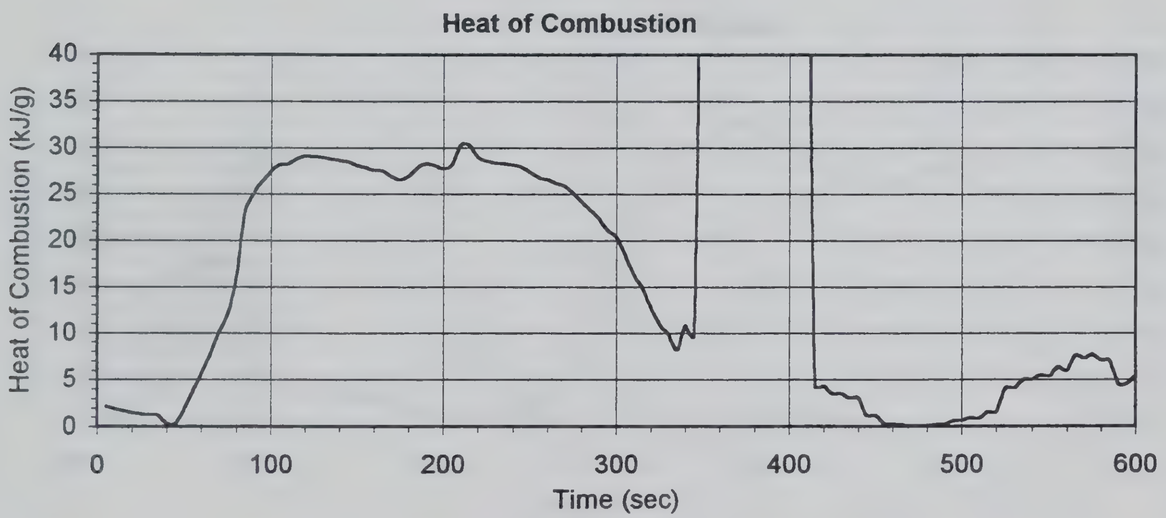


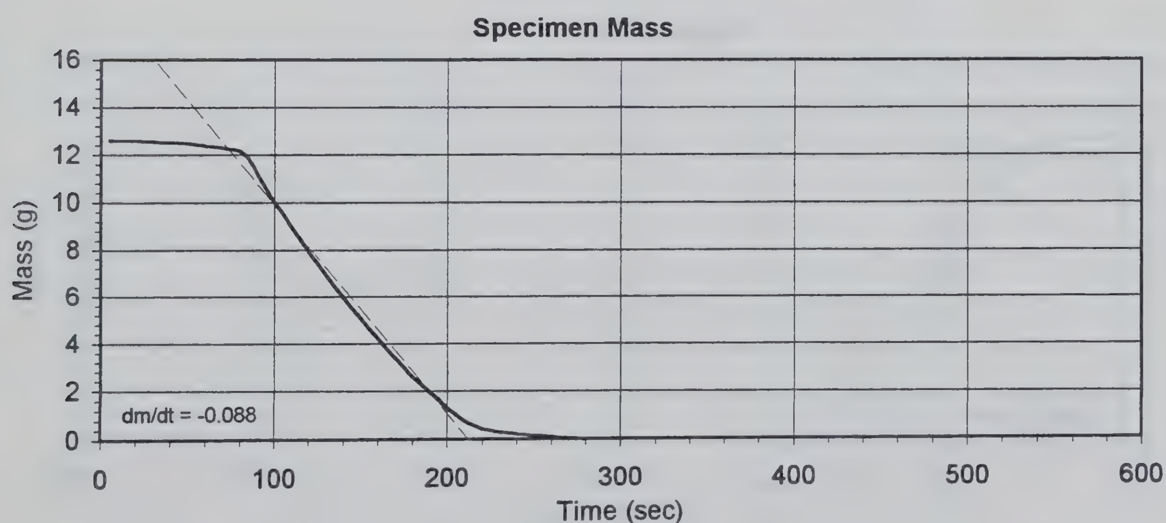




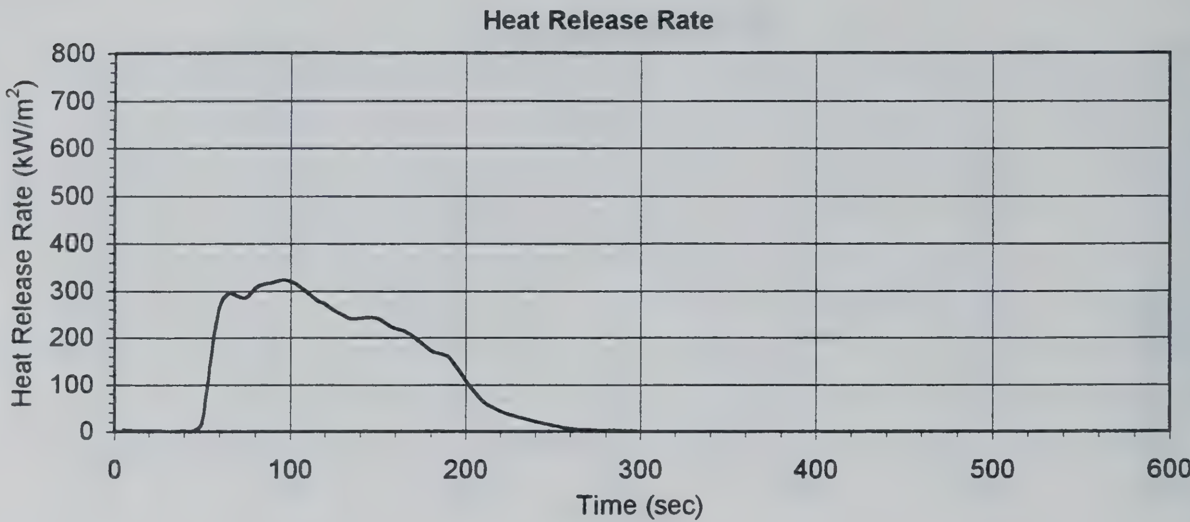
Cone Calorimeter Data R 4.05 F.R. Extruded Polystyrene Board (40 mm)
35 kW/m^2, Test #3

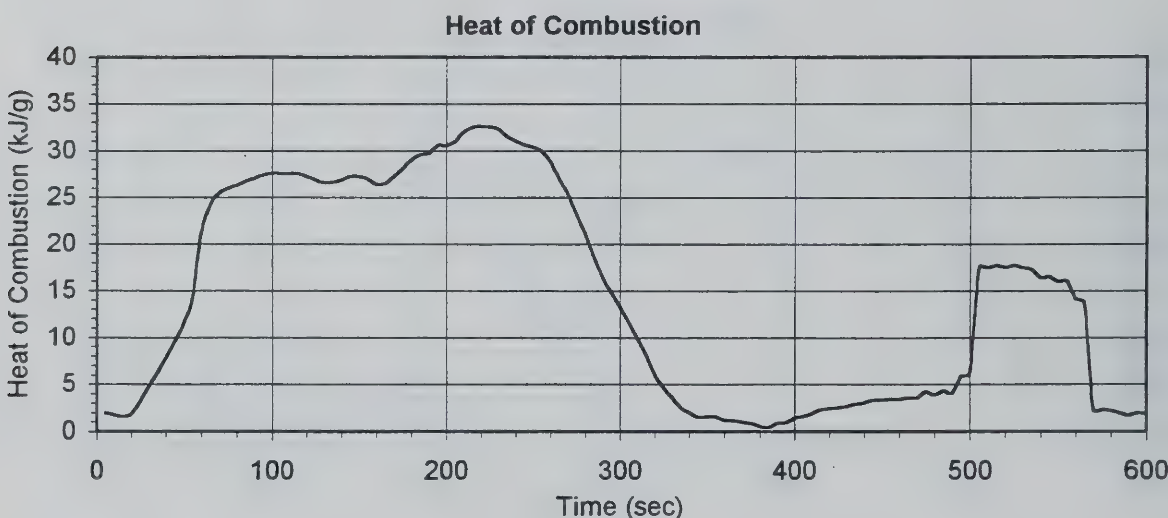


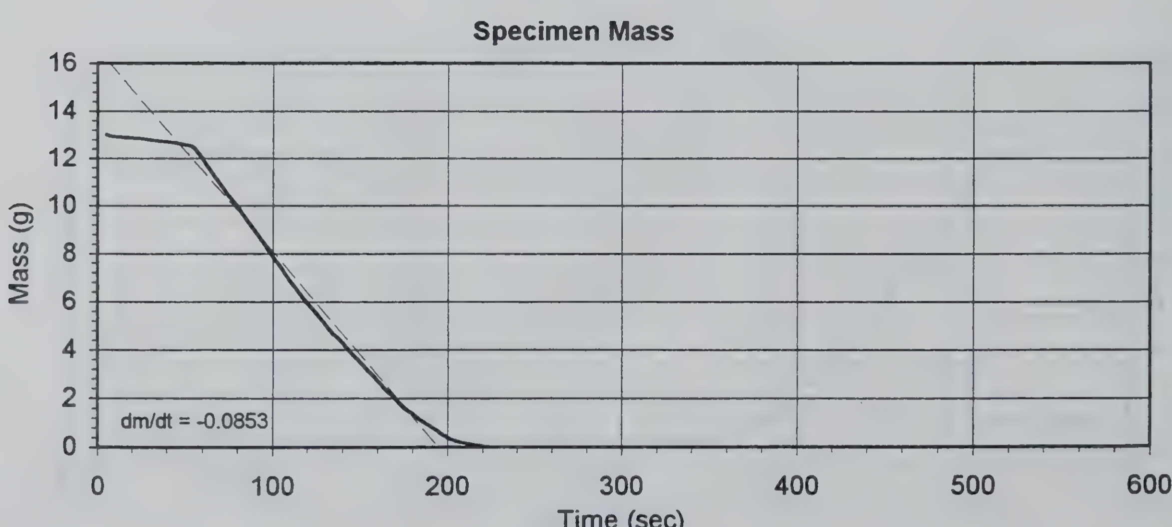




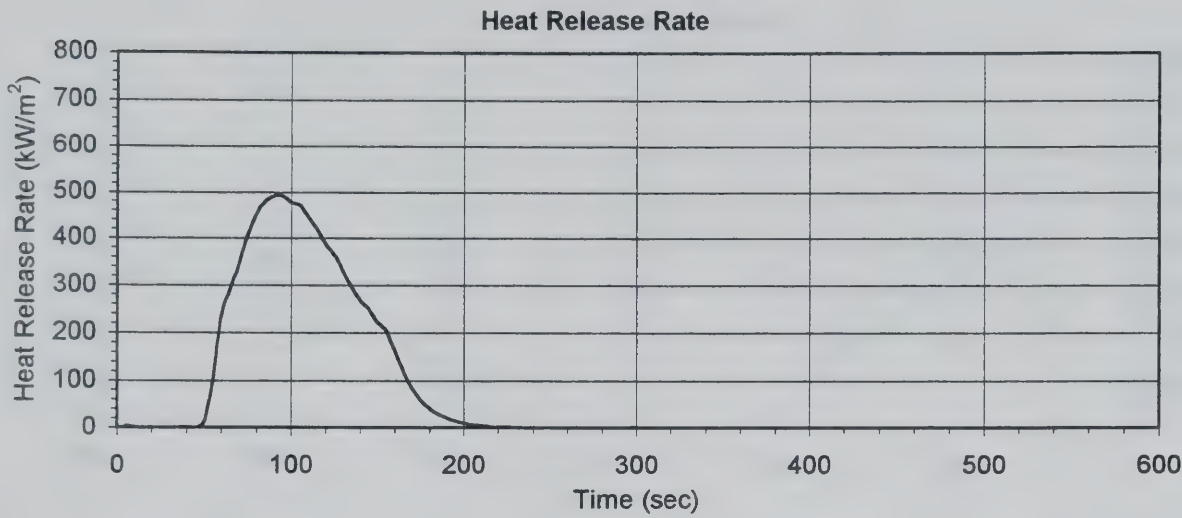
Cone Calorimeter Data R 4.05 F.R. Extruded Polystyrene Board (40 mm)
40 kW/m^2, Test #1

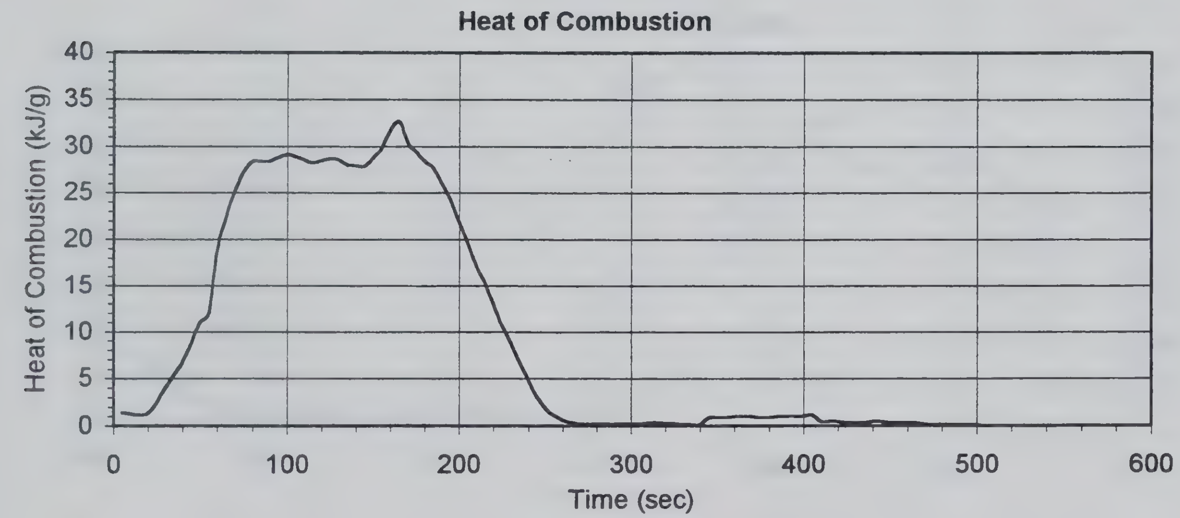


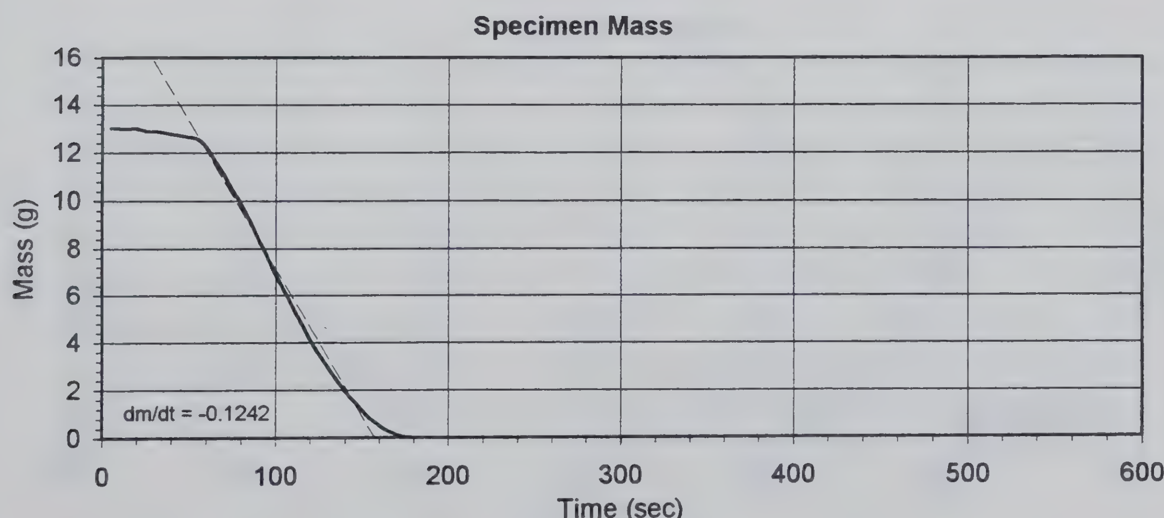




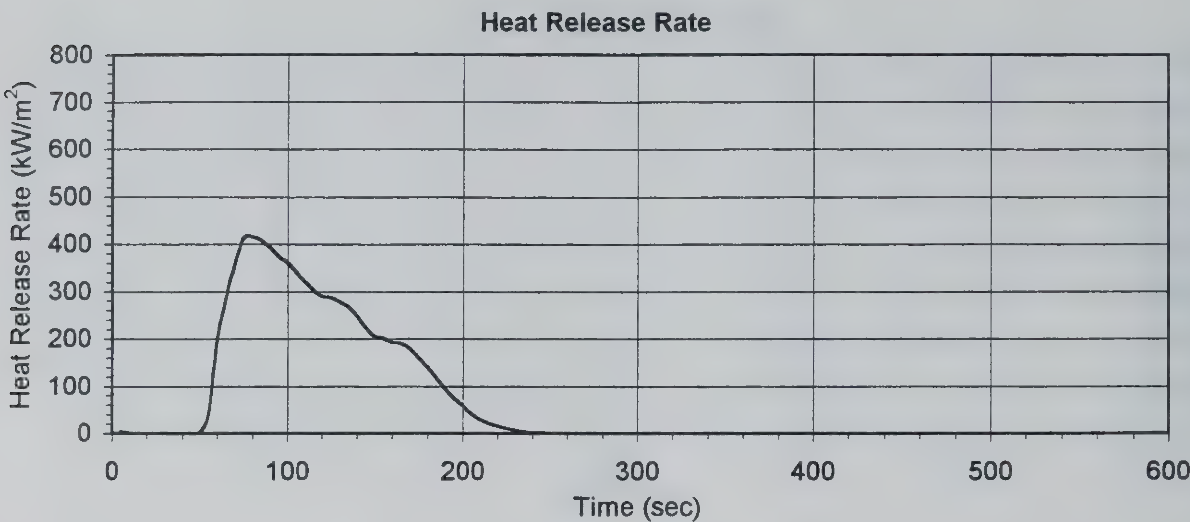
Cone Calorimeter Data R 4.05 F.R. Extruded Polystyrene Board (40 mm)
40 kW/m^2, Test #2

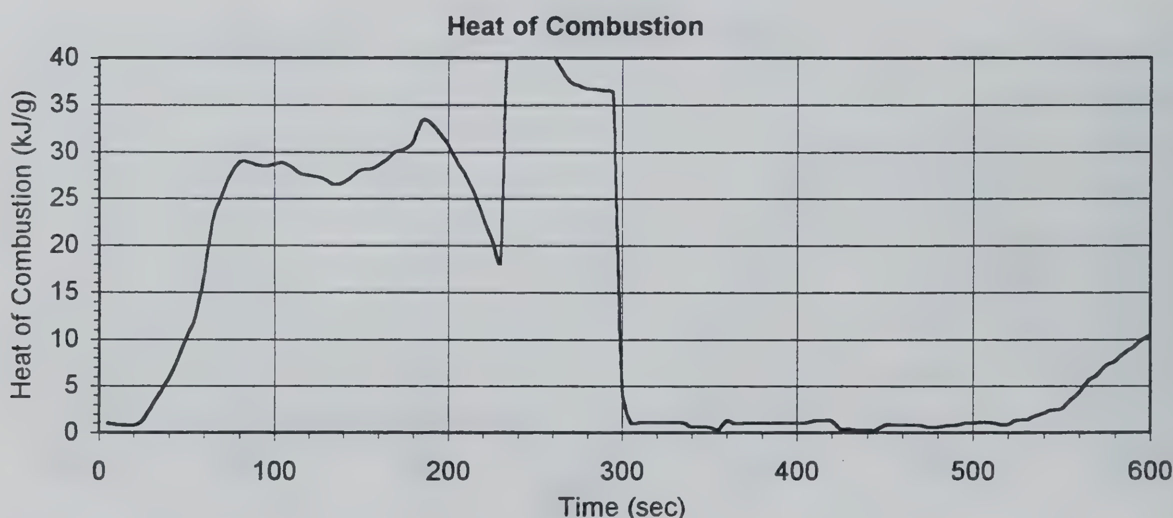


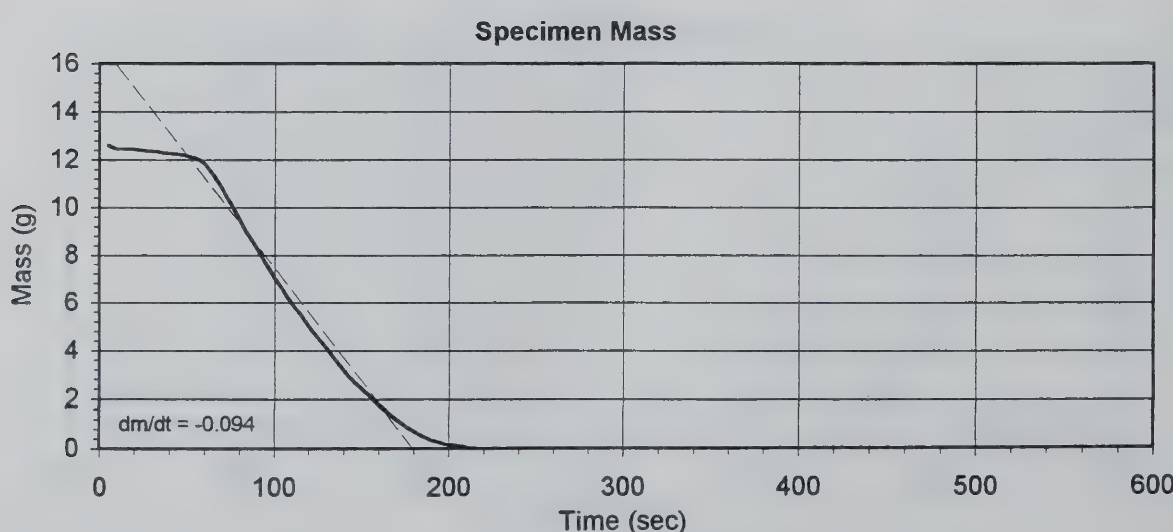




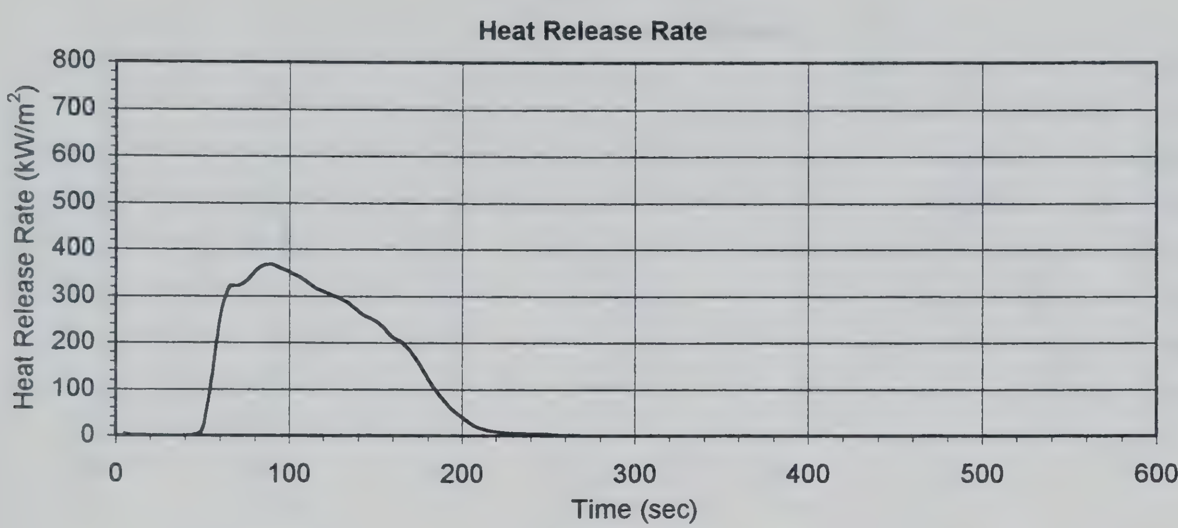
Cone Calorimeter Data R 4.05 F.R. Extruded Polystyrene Board (40 mm)
40 kW/m^2, Test #3

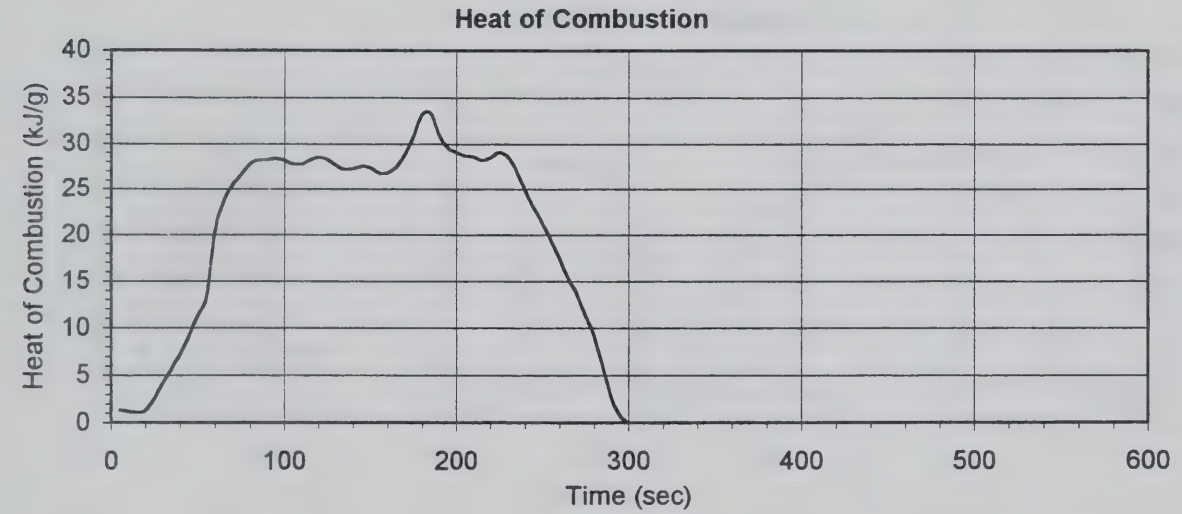


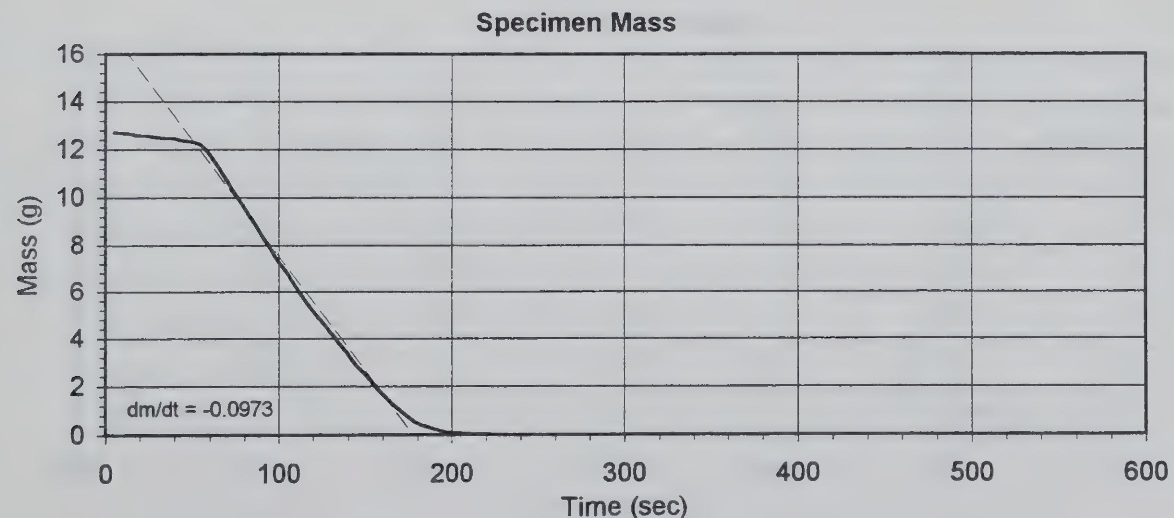




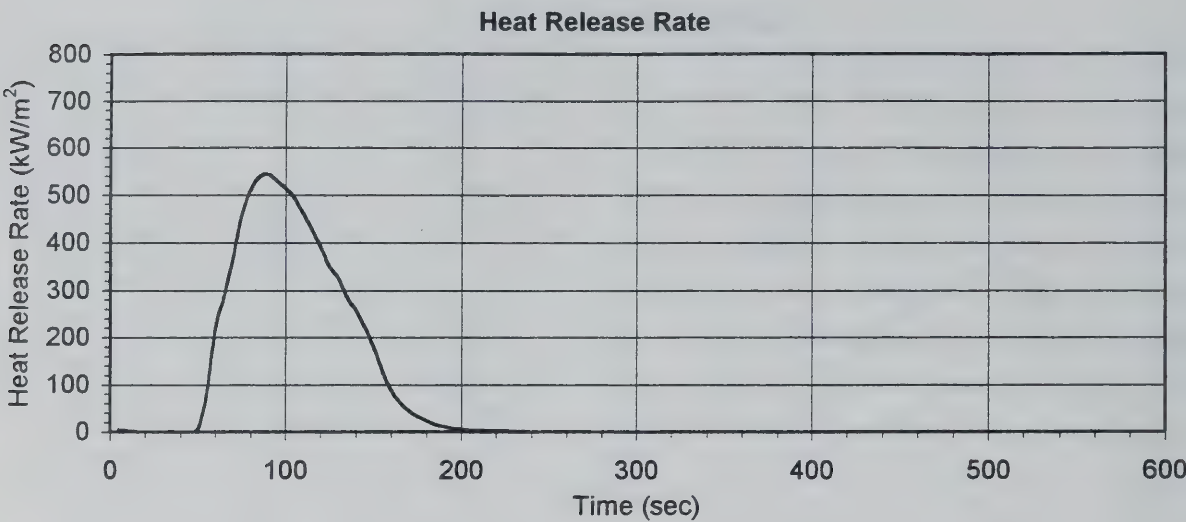
Cone Calorimeter Data R 4.05 F.R. Extruded Polystyrene Board (40 mm)
40 kW/m^2, Test #4

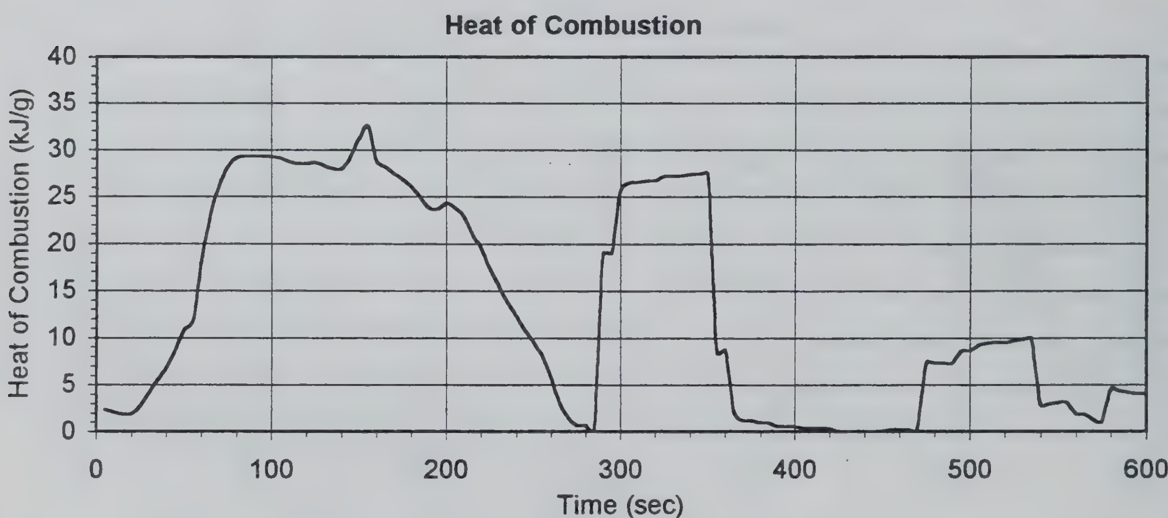


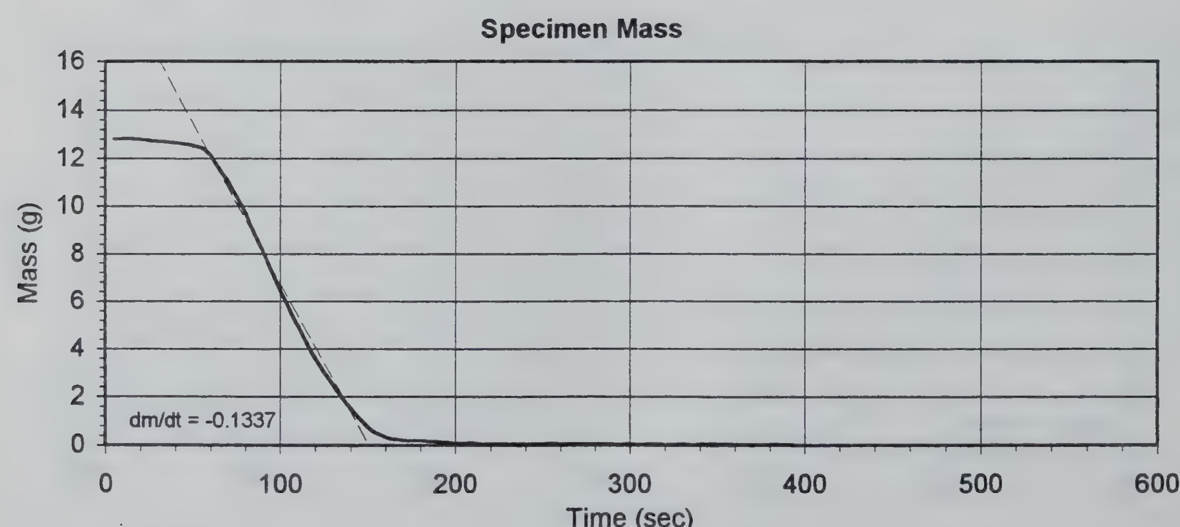




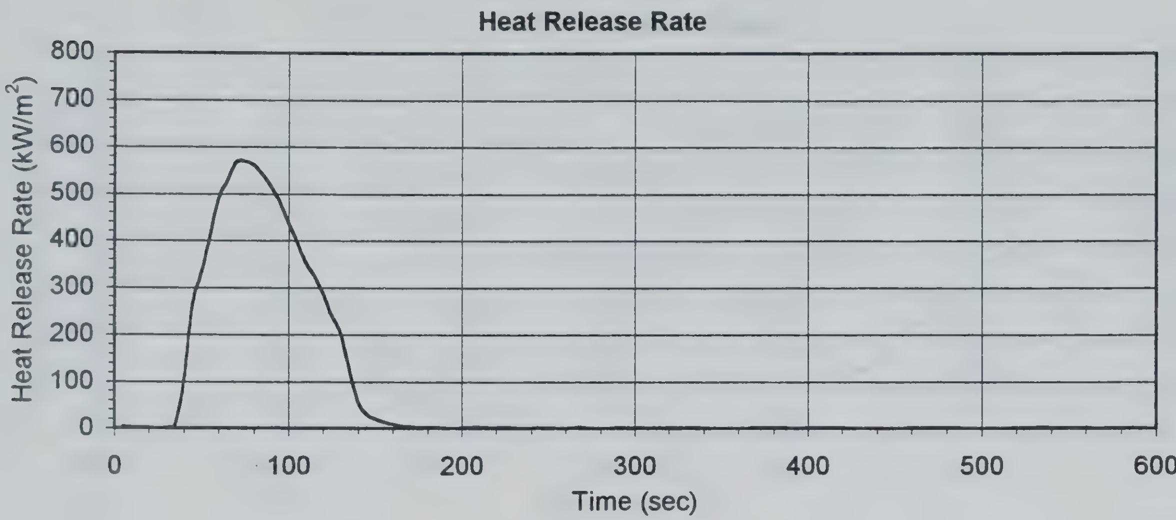
Cone Calorimeter Data R 4.05 F.R. Extruded Polystyrene Board (40 mm)
40 kW/m², Test #5

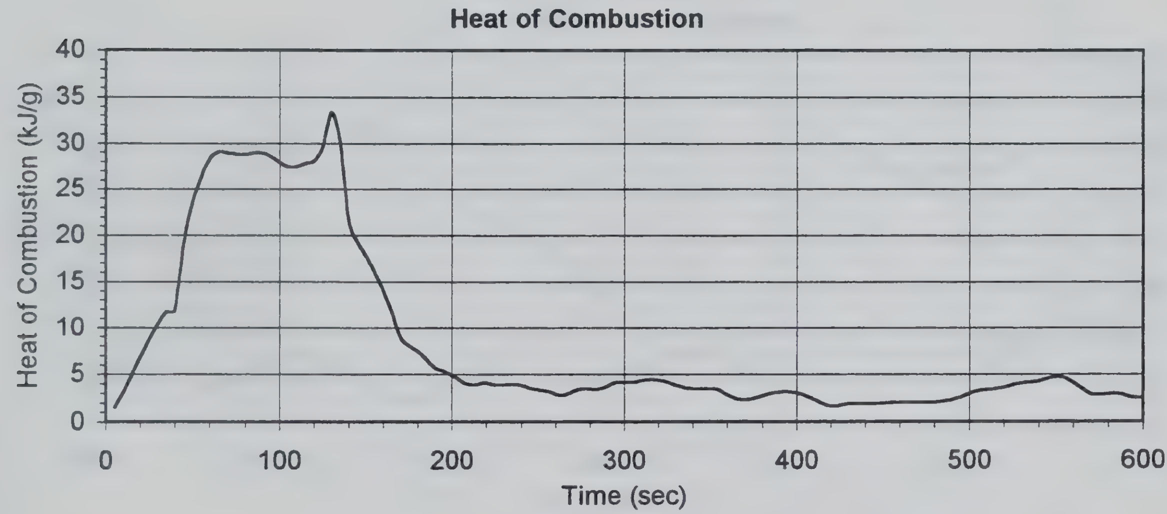


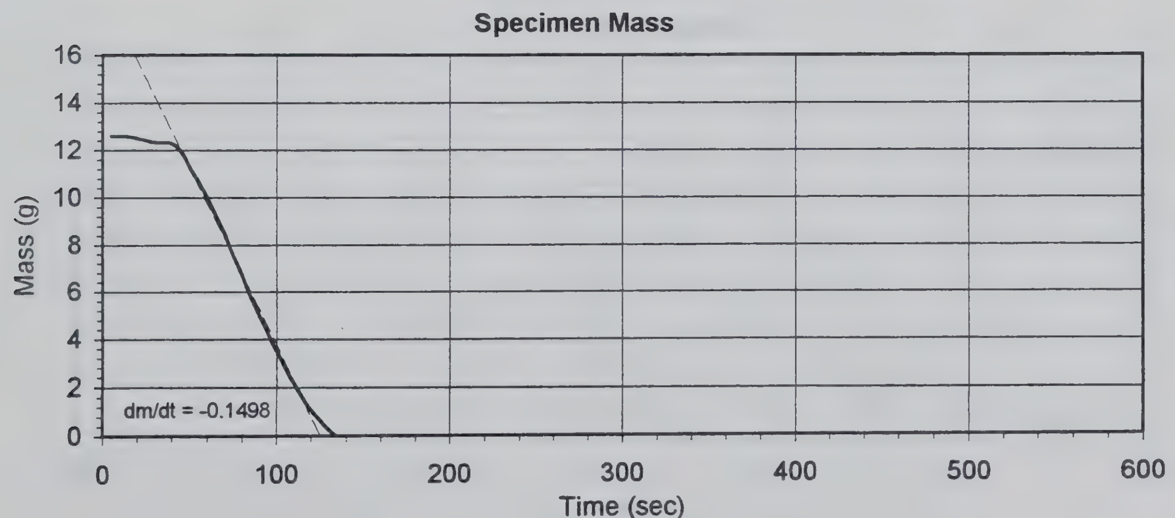




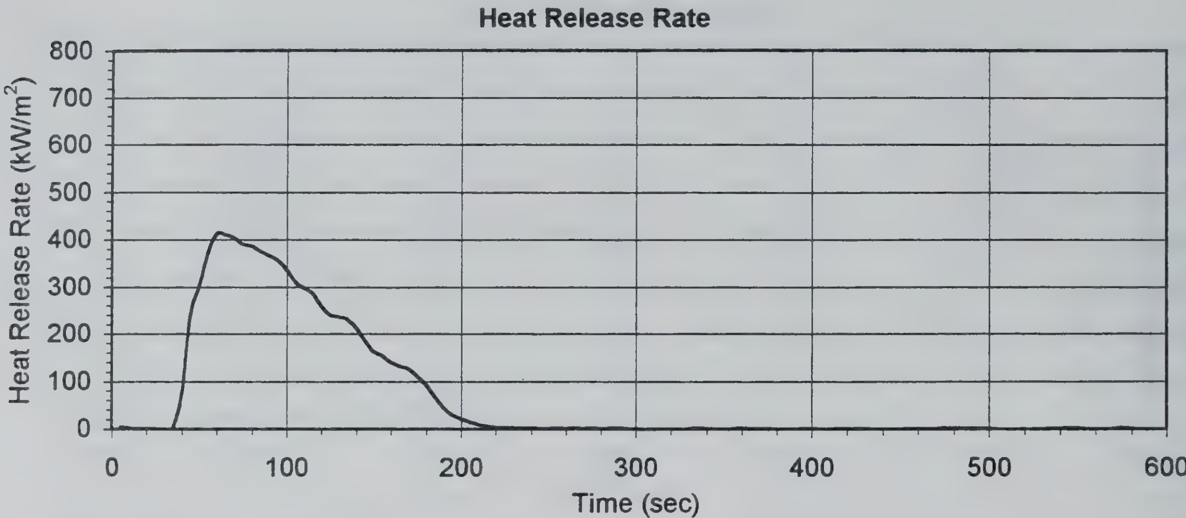
Cone Calorimeter Data R 4.05 F.R. Extruded Polystyrene Board (40 mm)
50 kW/m^2, Test #1

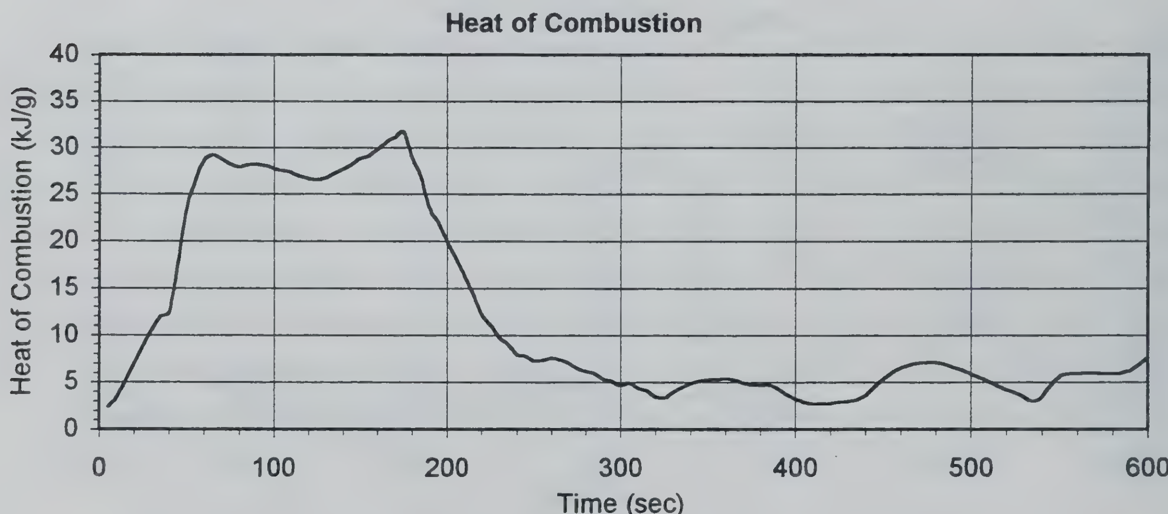


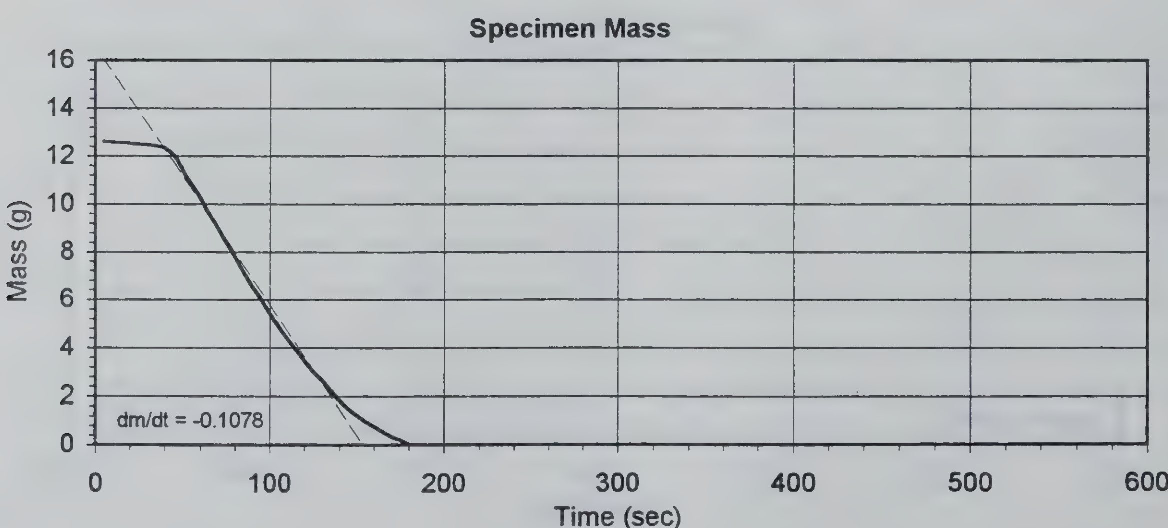




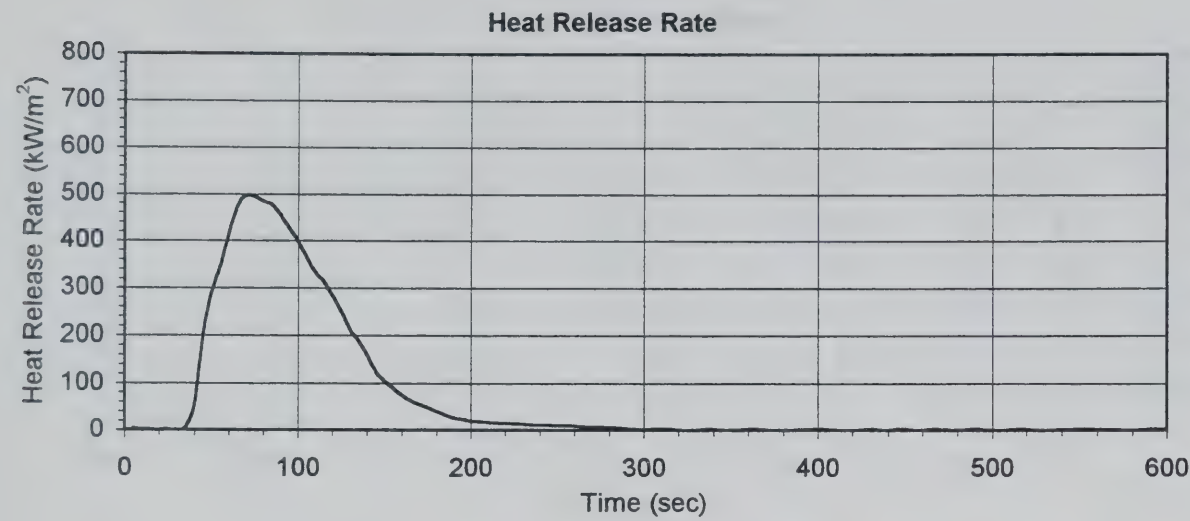
Cone Calorimeter Data R 4.05 F.R. Extruded Polystyrene Board (40 mm)
50 kW/m^2, Test #2

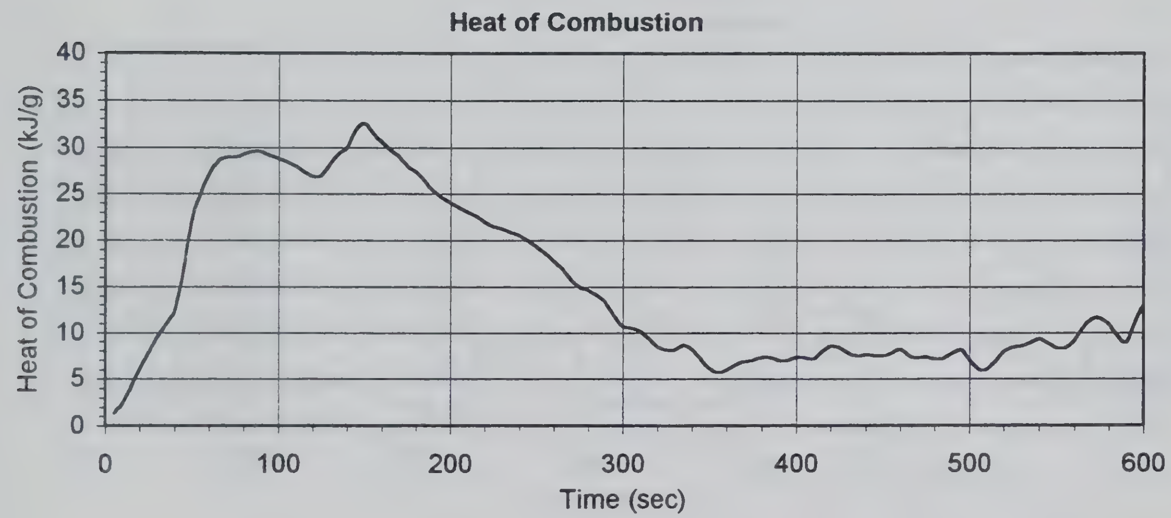


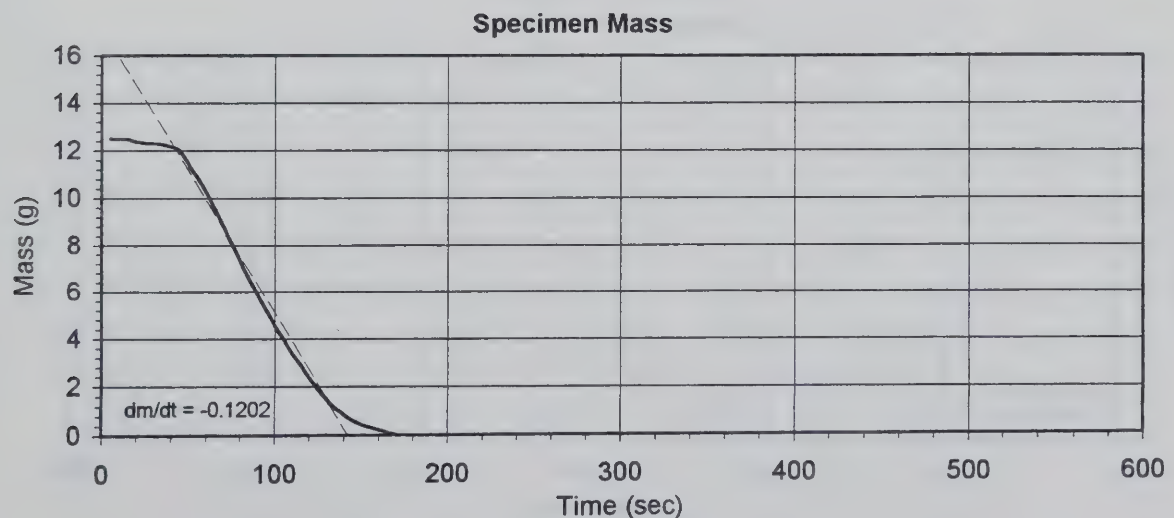




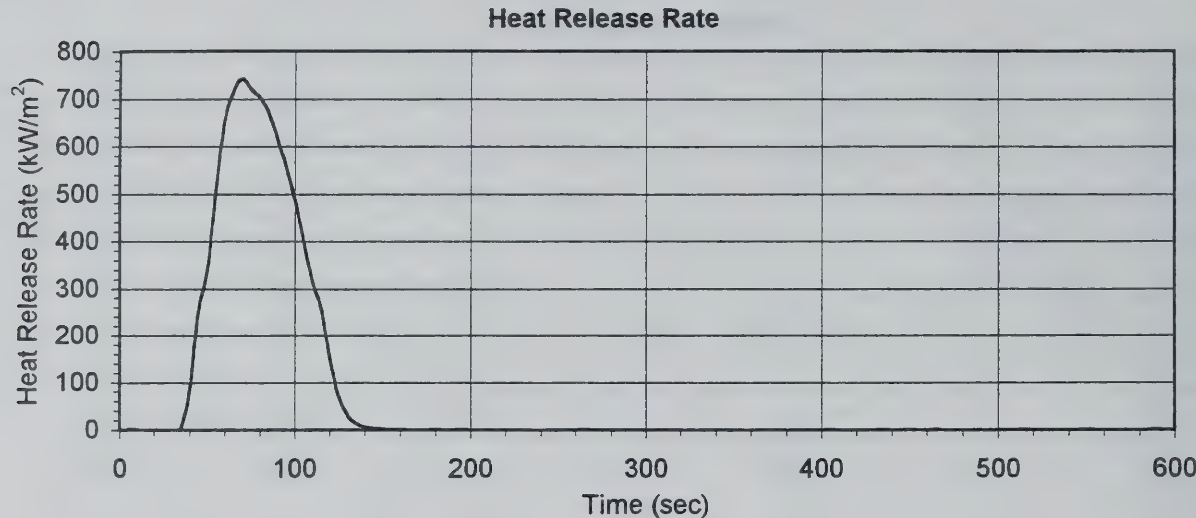
Cone Calorimeter Data R 4.05 F.R. Extruded Polystyrene Board (40 mm)
50 kW/m^2, Test #3

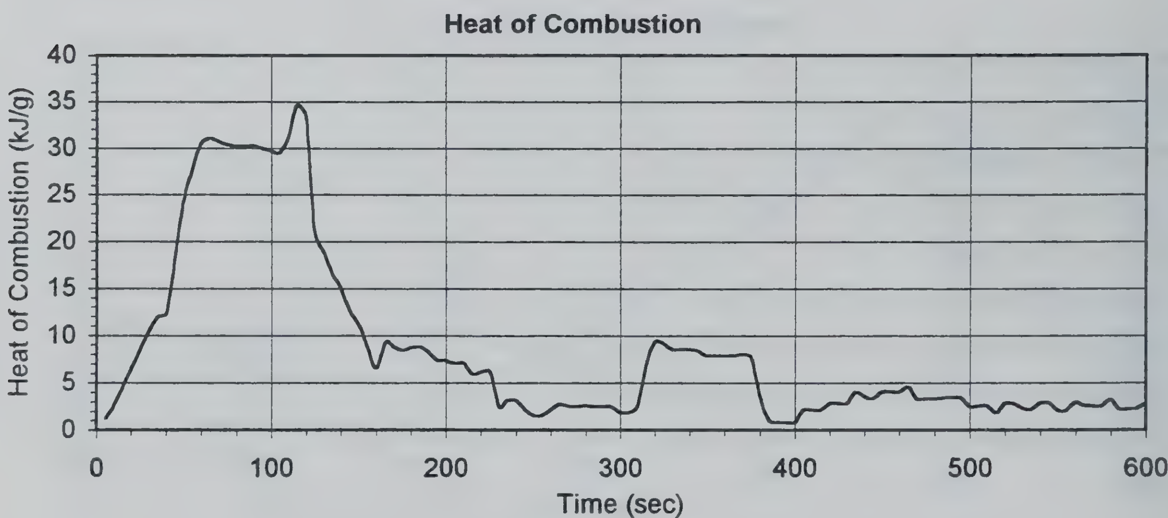


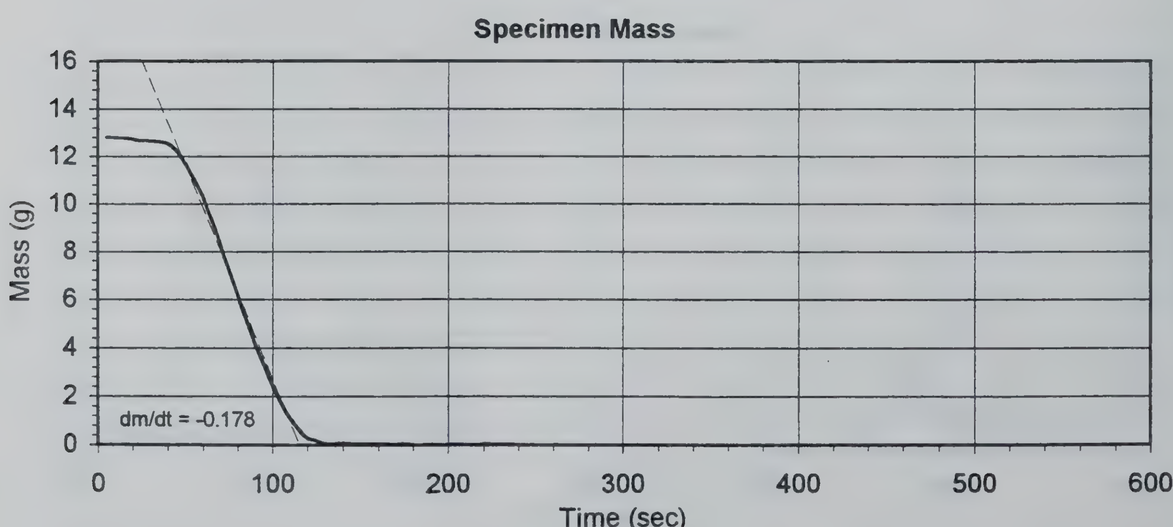




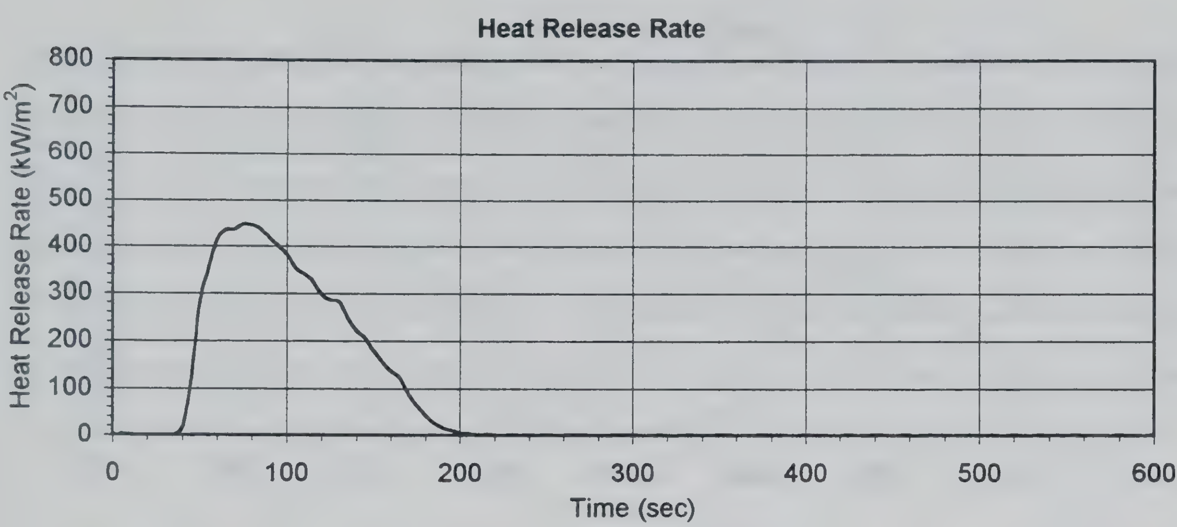
Cone Calorimeter Data R 4.05 F.R. Extruded Polystyrene Board (40 mm)
50 kW/m^2, Test #4

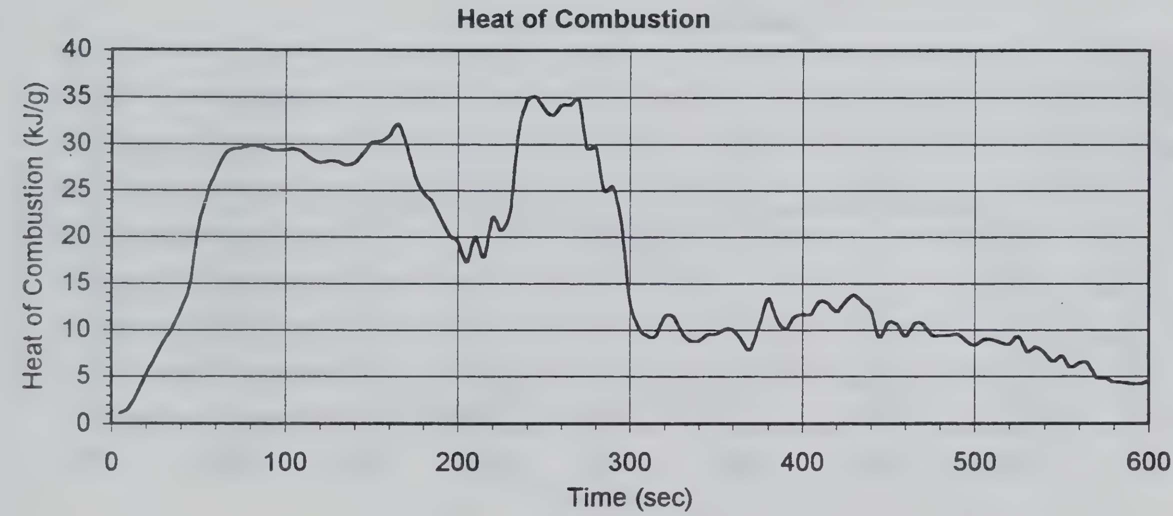


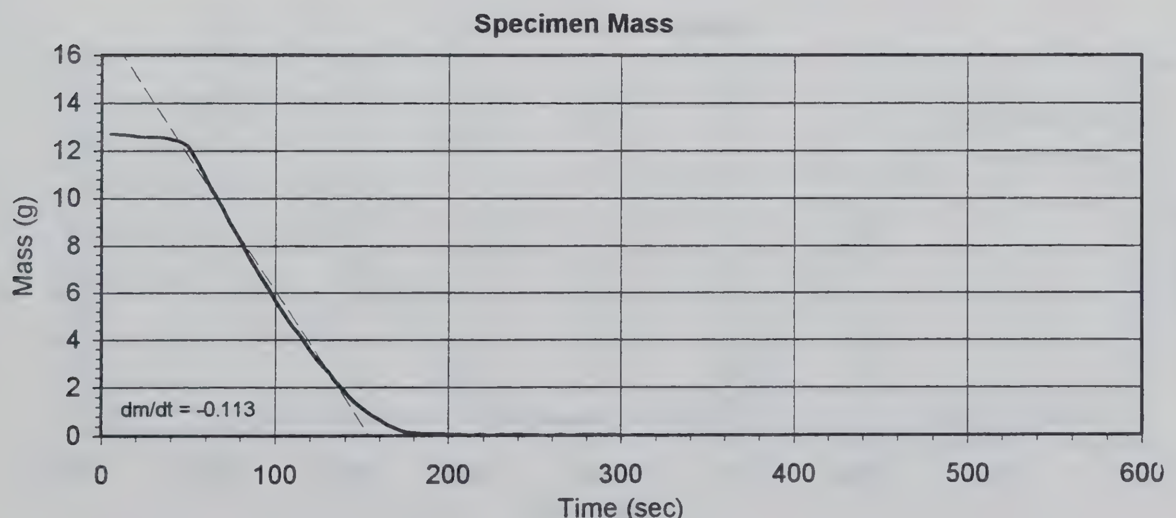




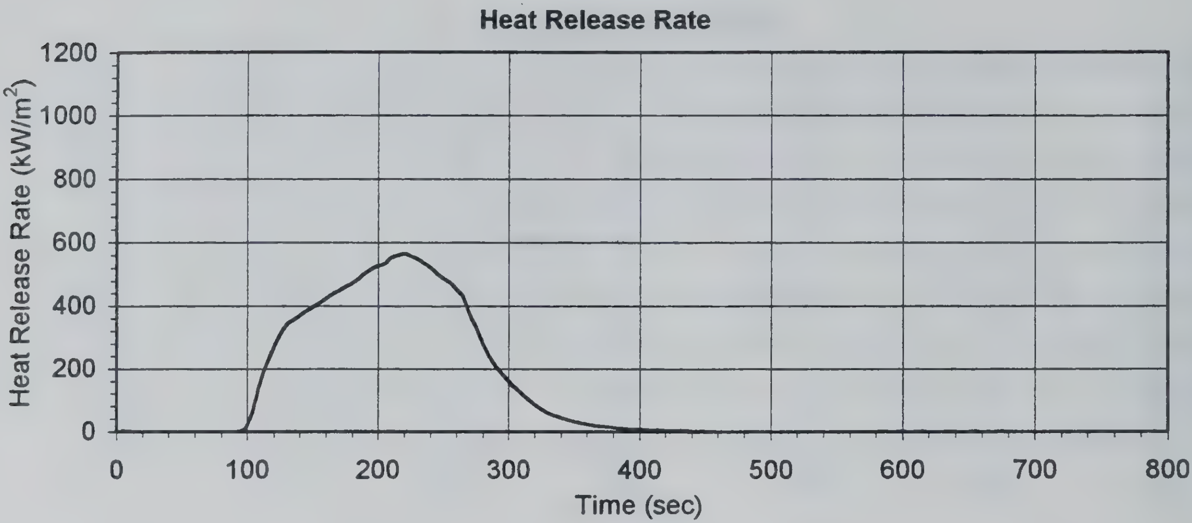
Cone Calorimeter Data R 4.05 F.R. Extruded Polystyrene Board (40 mm)
50 kW/m^2, Test #5

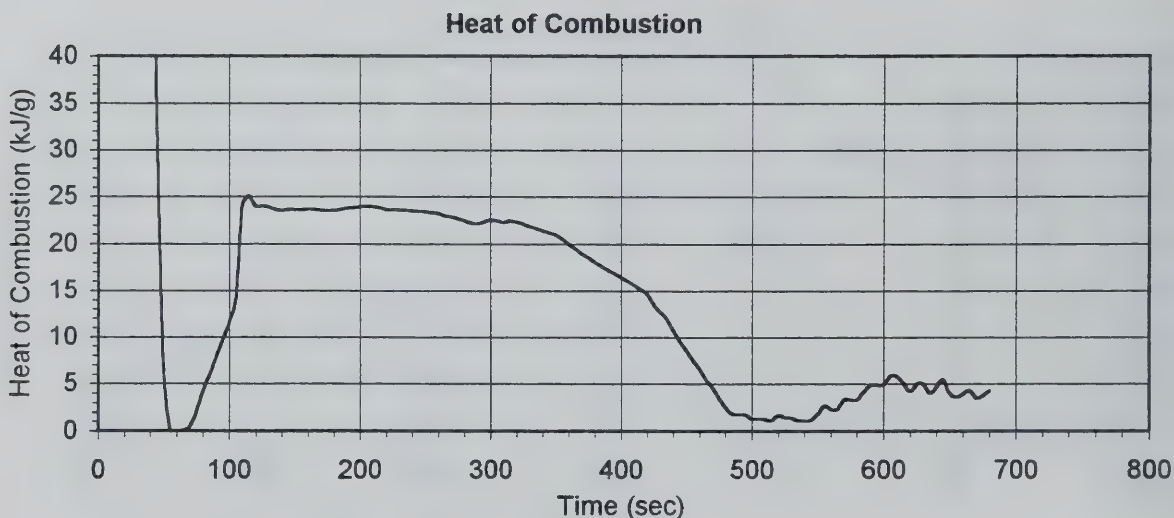


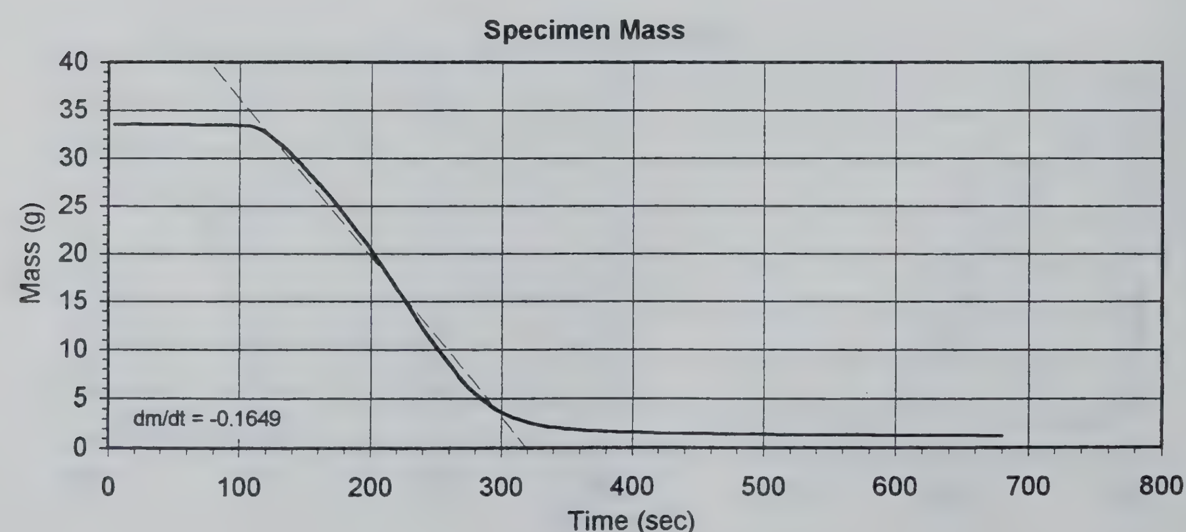




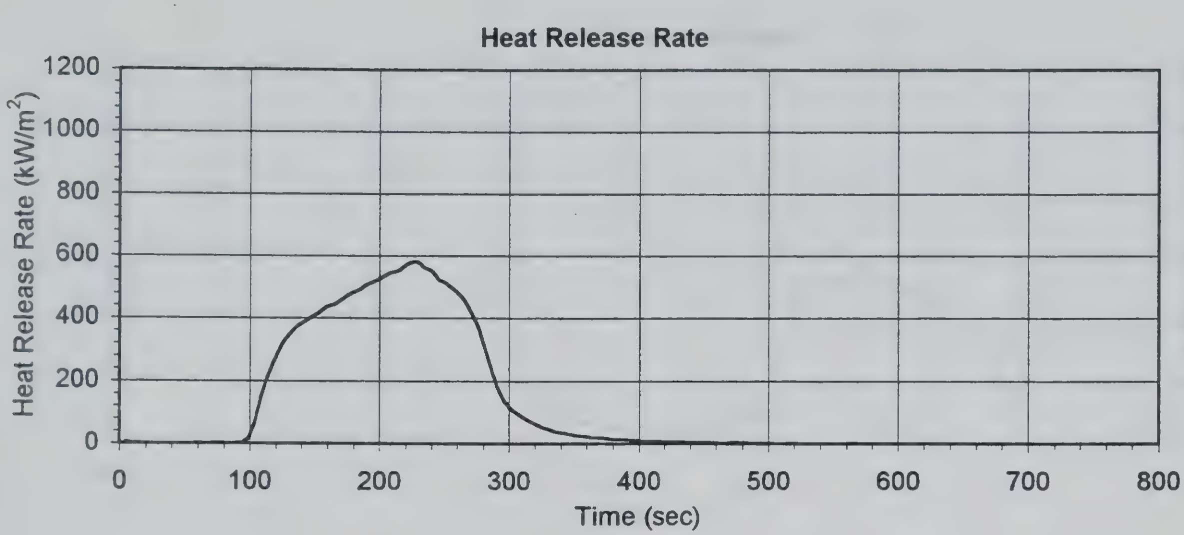
Cone Calorimeter Data R 4.06 Acrylic Glazing
25 kW/m^2, Test #1

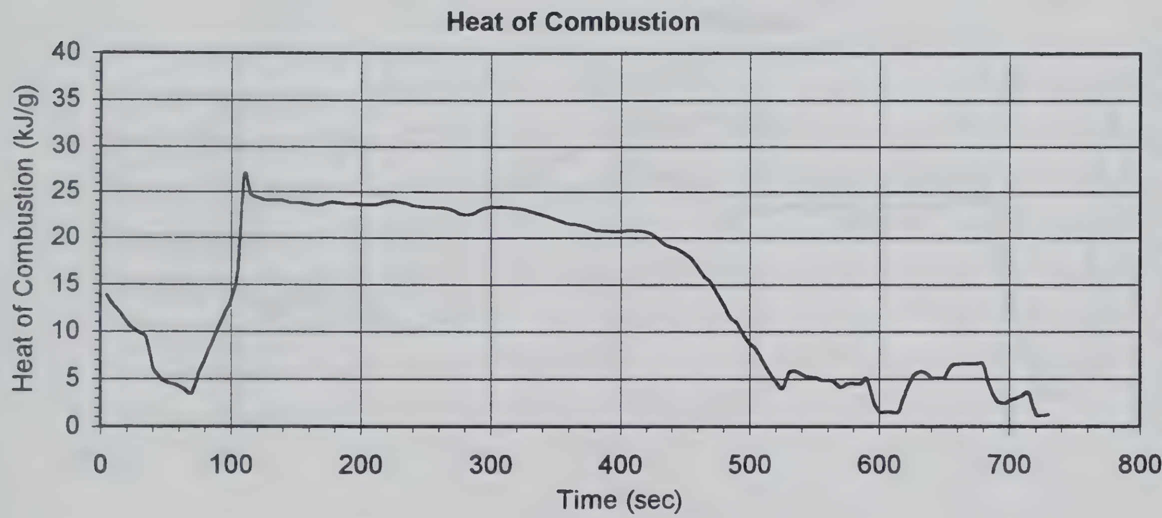


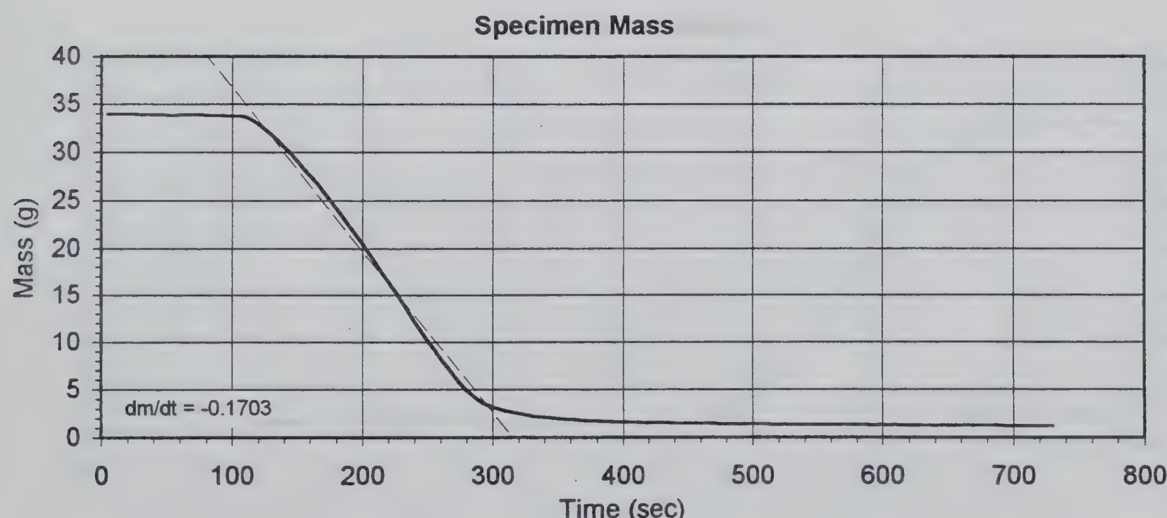




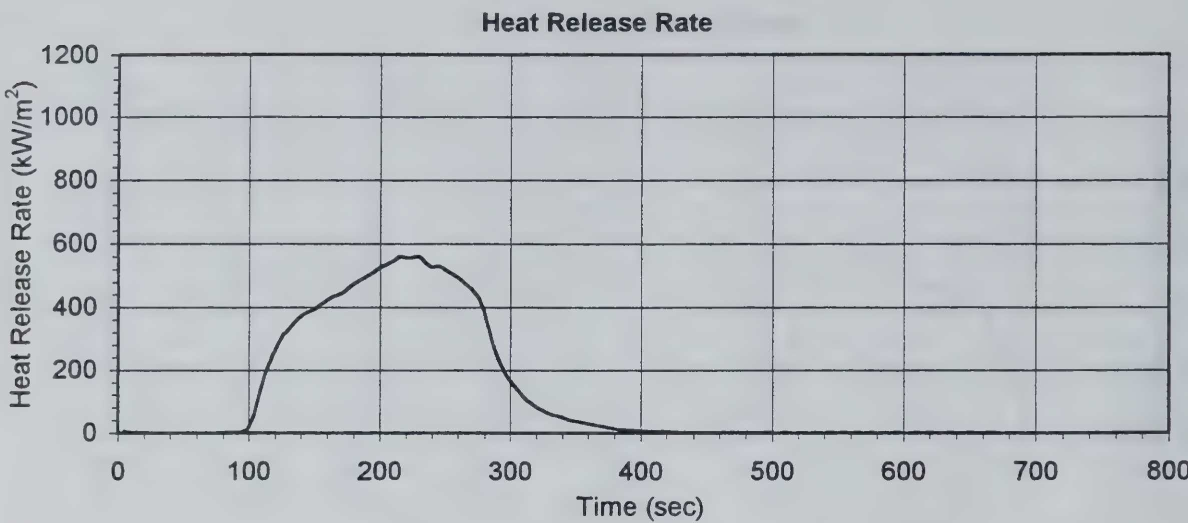
Cone Calorimeter Data R 4.06 Acrylic Glazing
25 kW/m^2, Test #2

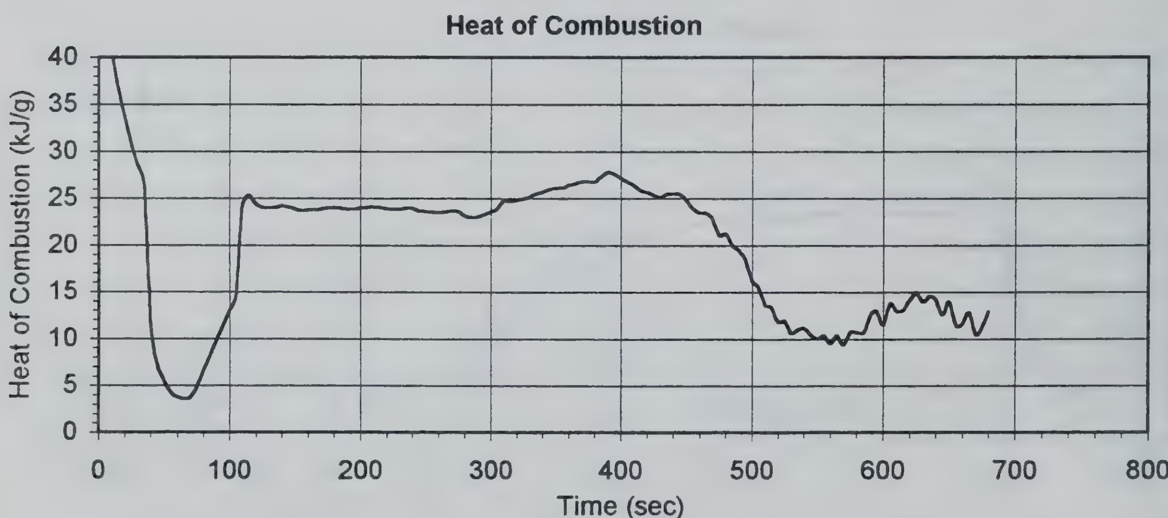


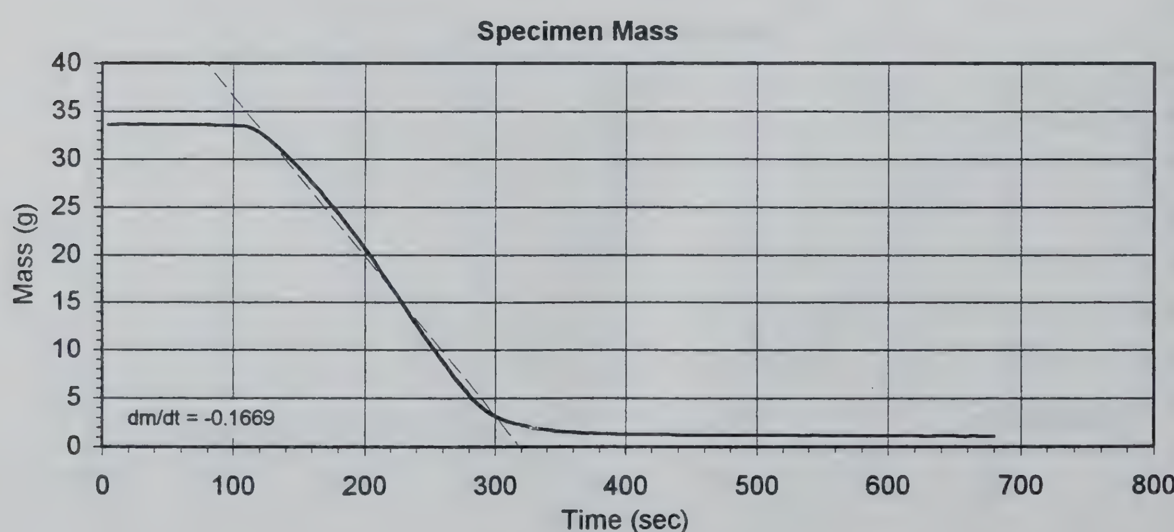




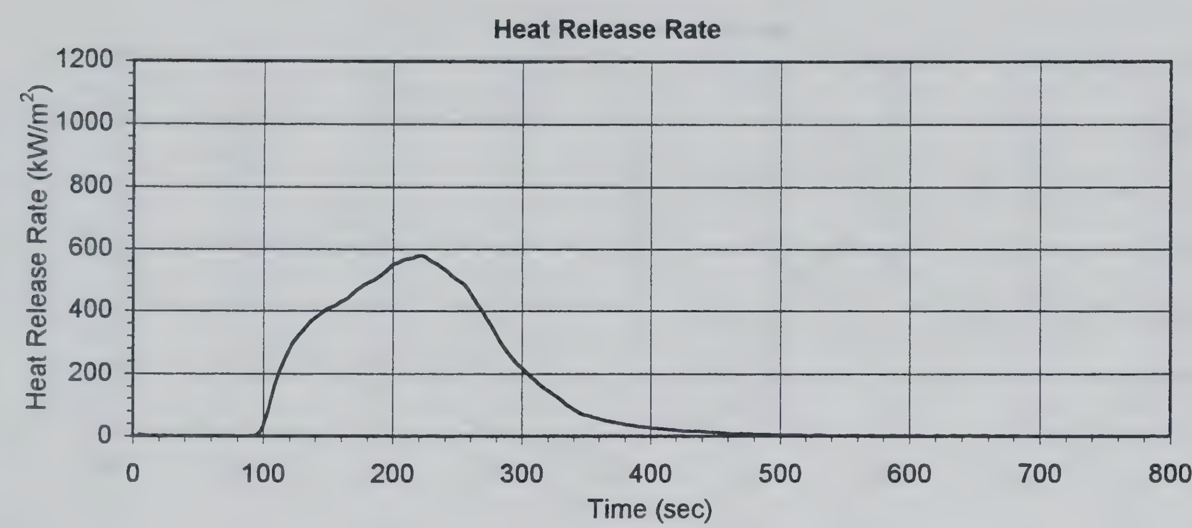
Cone Calorimeter Data R 4.06 Acrylic Glazing
25 kW/m^2, Test #3

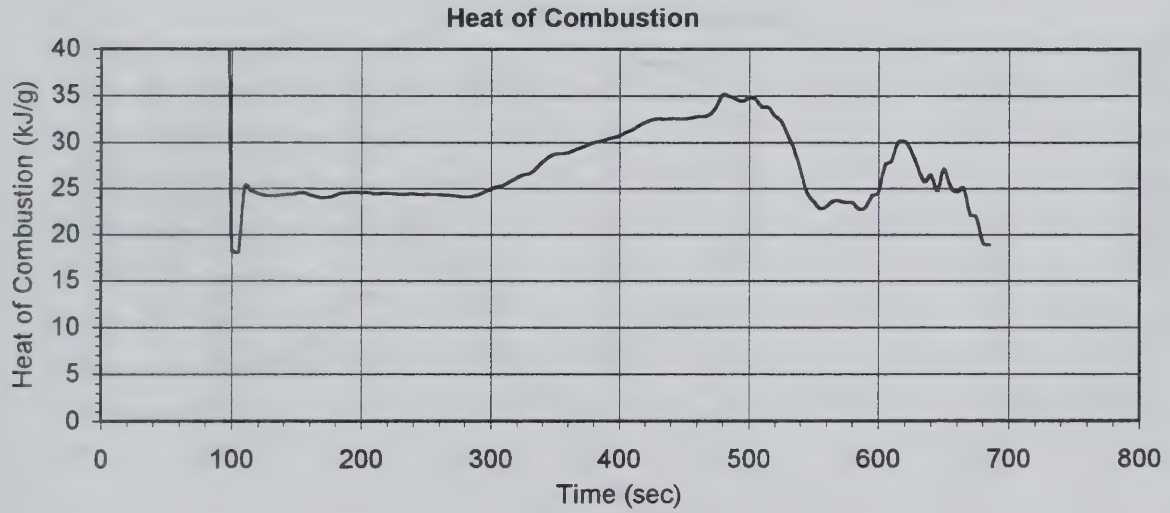


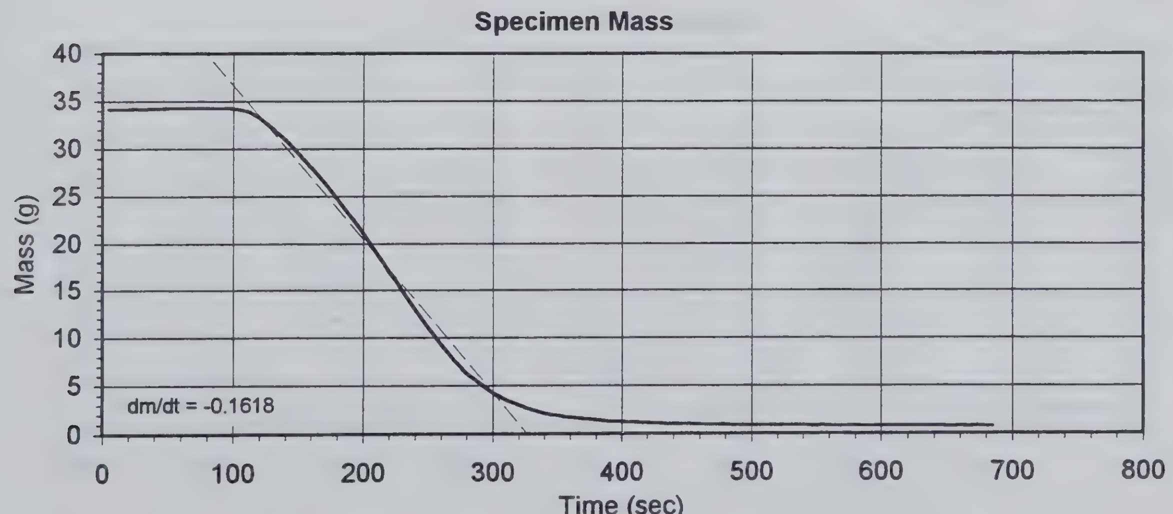




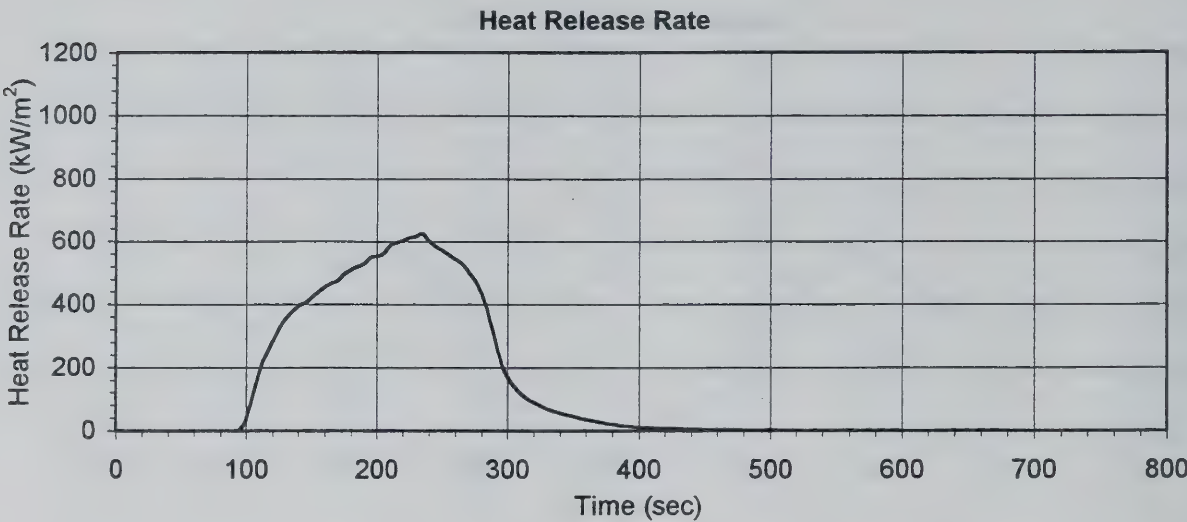
Cone Calorimeter Data R 4.06 Acrylic Glazing
25 kW/m², Test #4

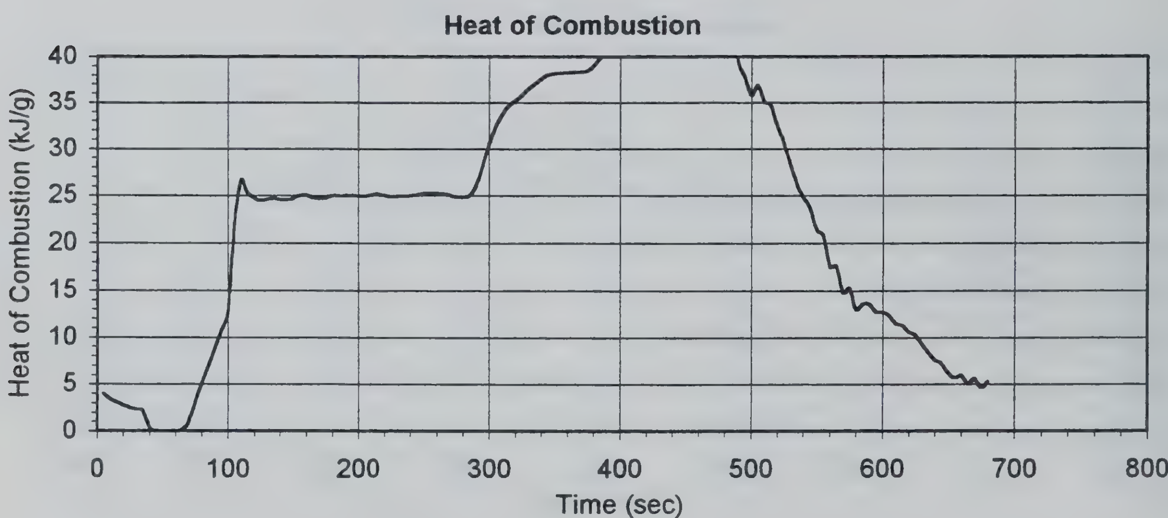


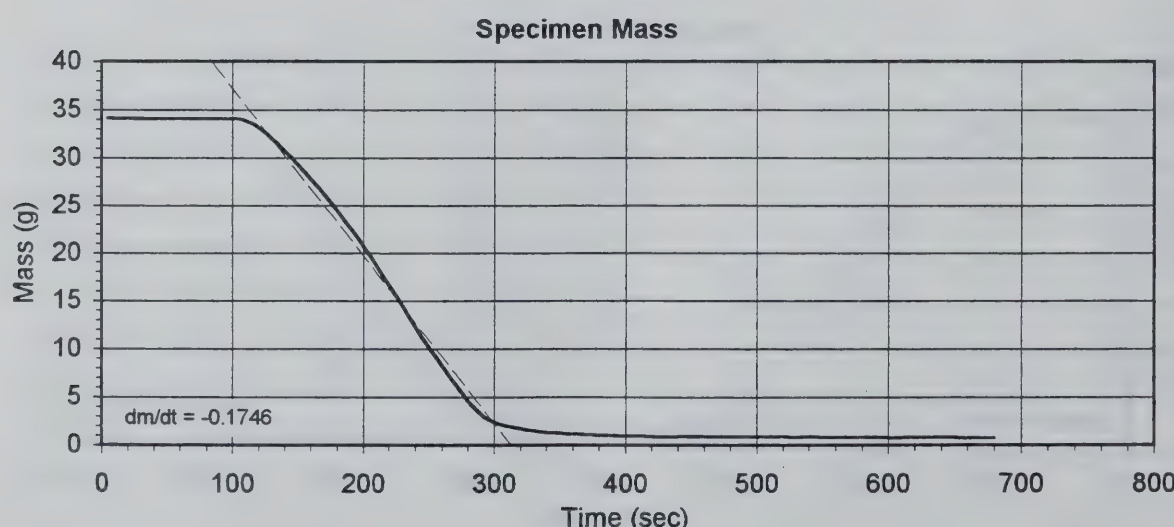




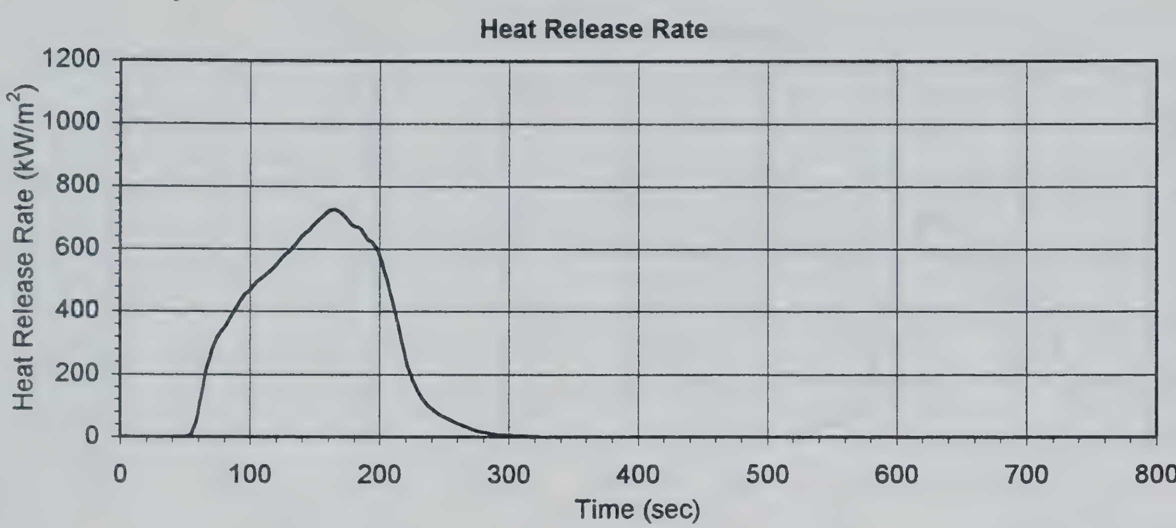
Cone Calorimeter Data R 4.06 Acrylic Glazing
25 kW/m^2, Test #5

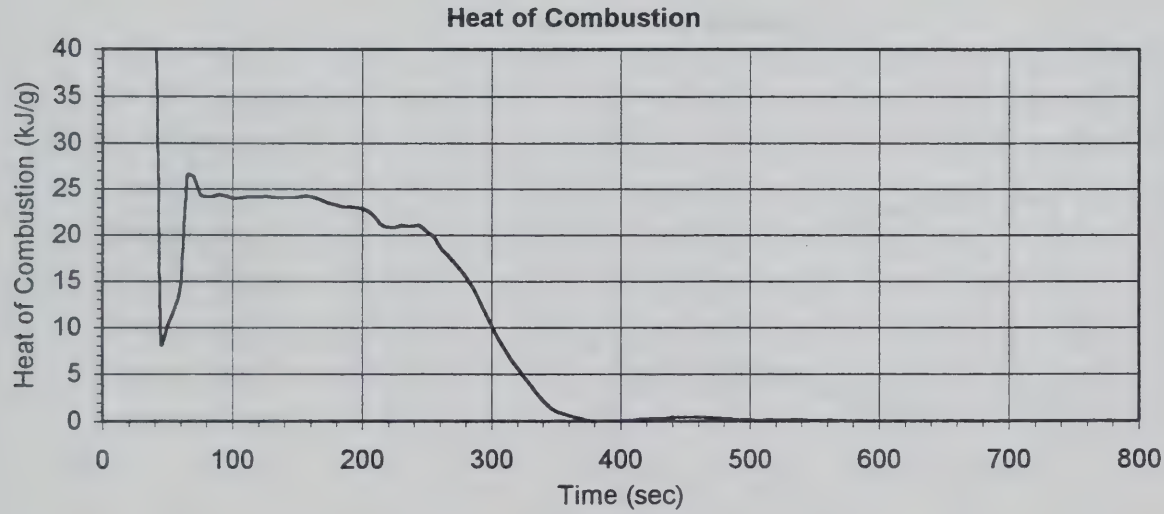


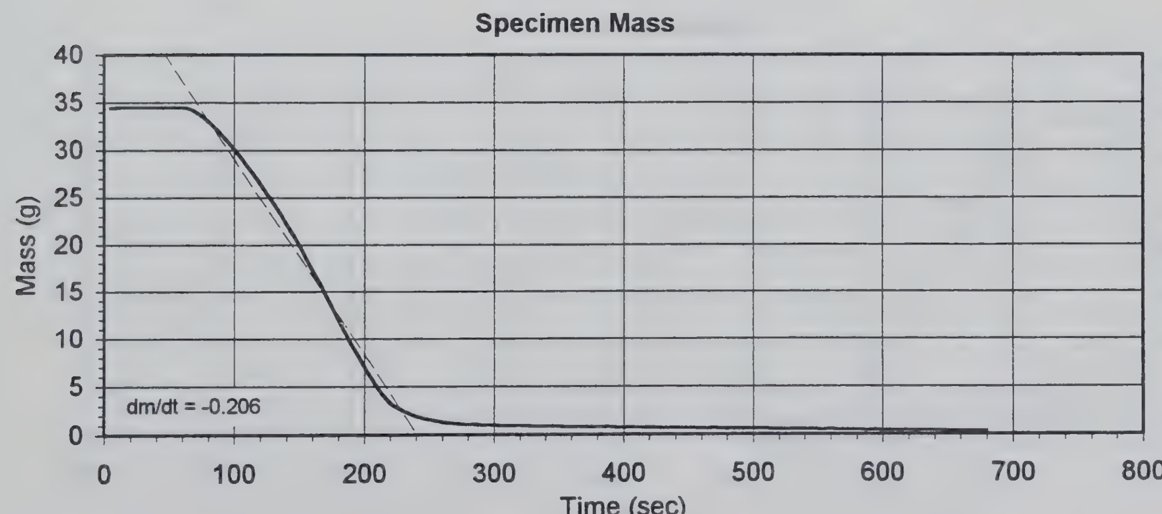




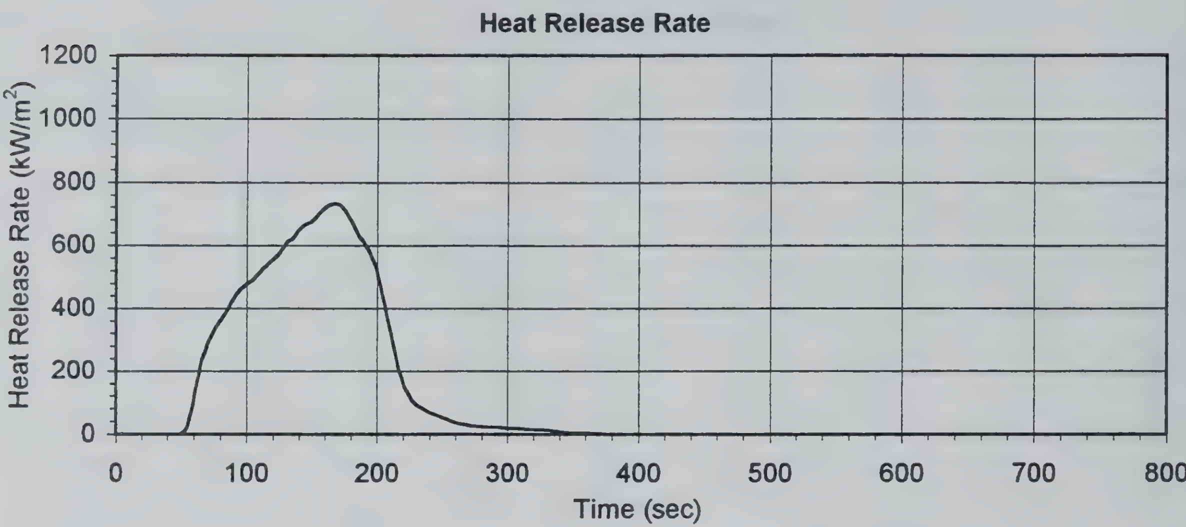
Cone Calorimeter Data R 4.06 Acrylic Glazing
35 kW/m^2, Test #1

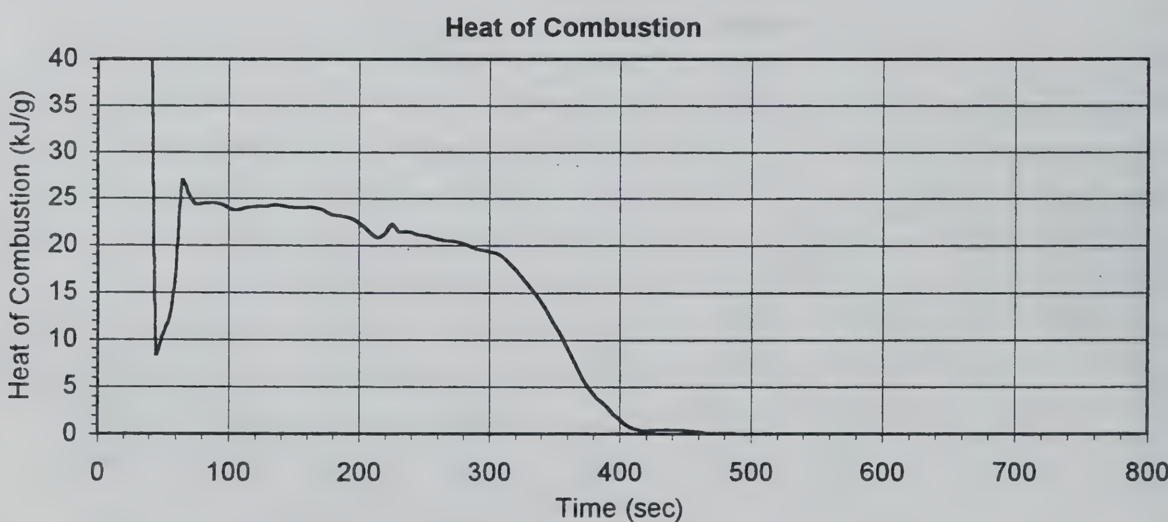


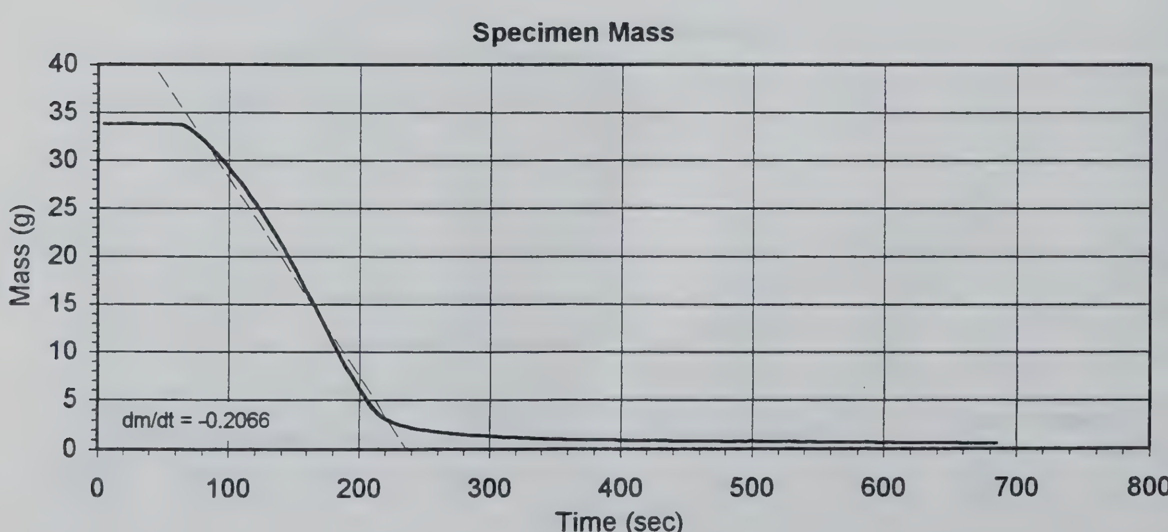




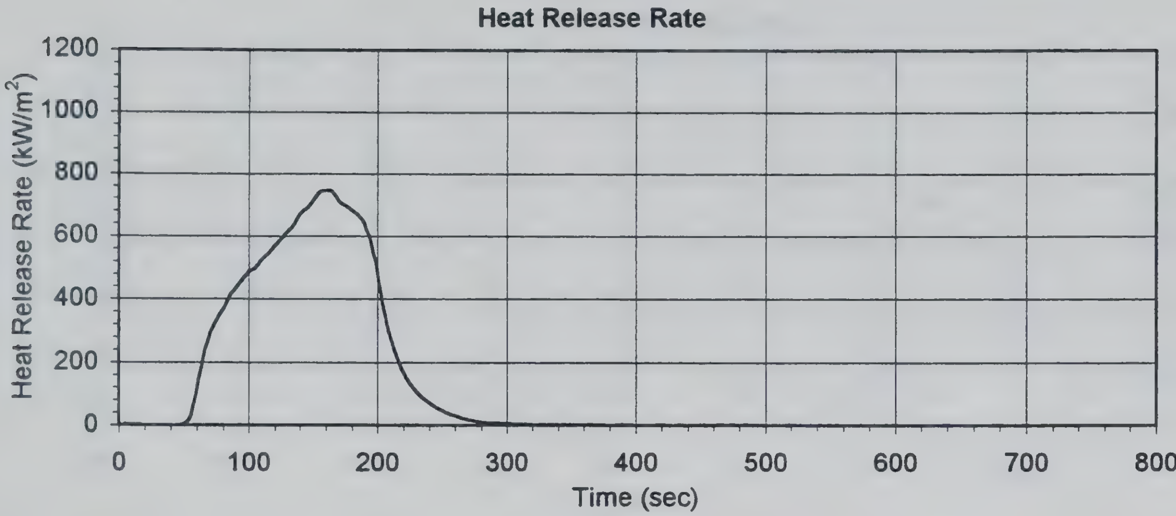
Cone Calorimeter Data R 4.06 Acrylic Glazing
35 kW/m^2, Test #2

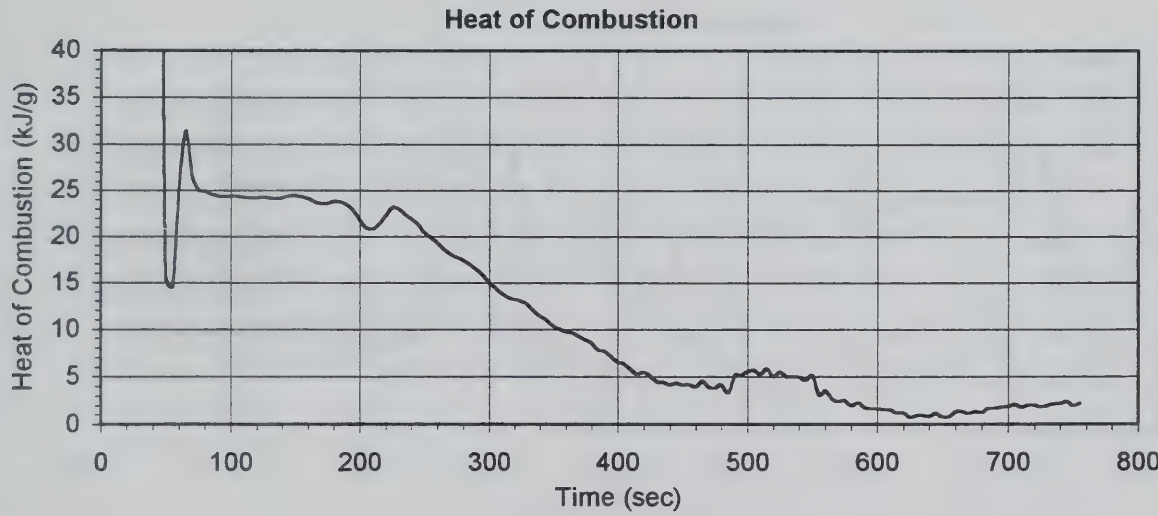


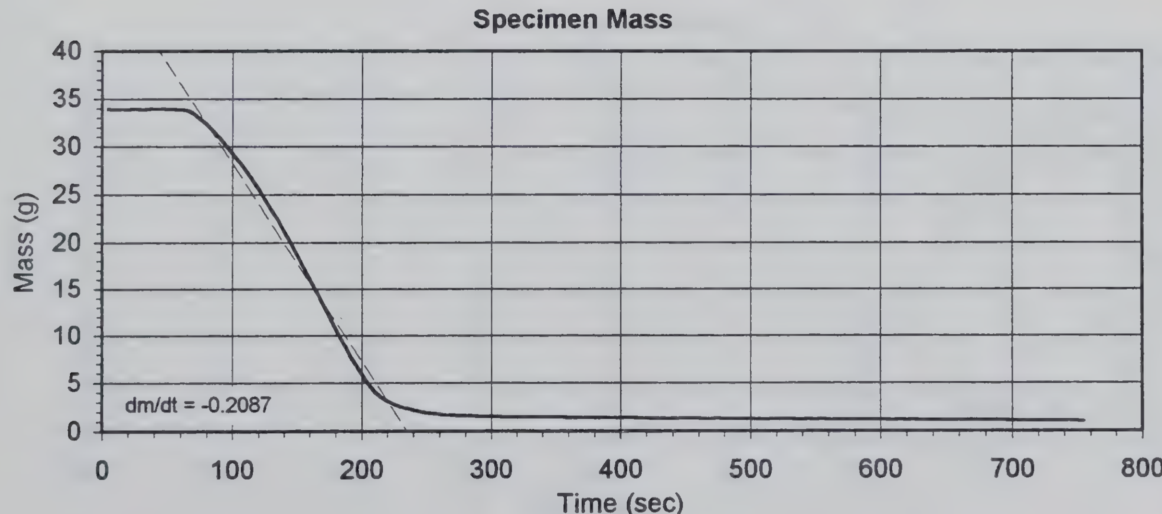




Cone Calorimeter Data R 4.06 Acrylic Glazing
35 kW/m^2, Test #3

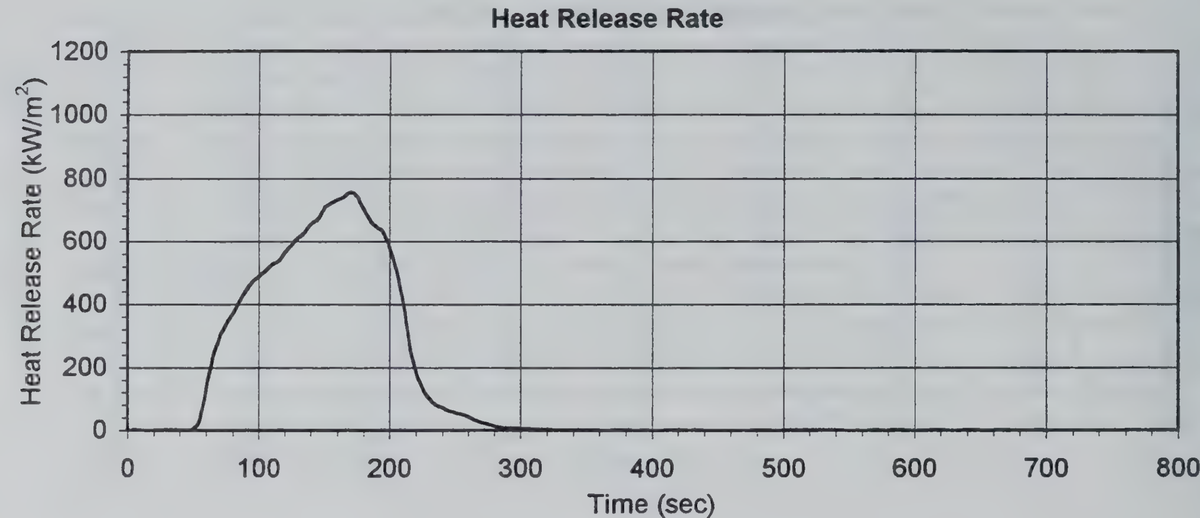


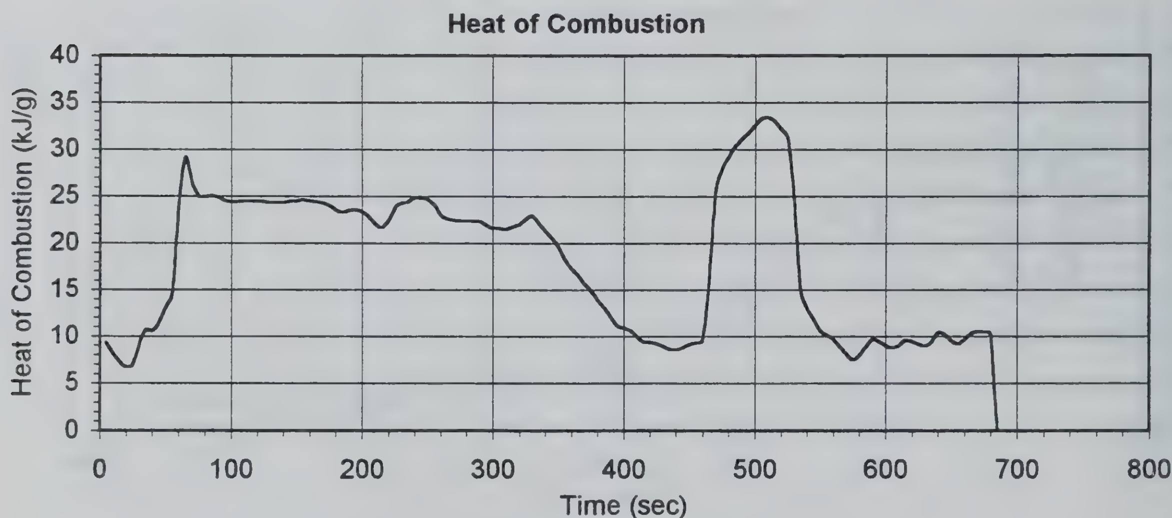


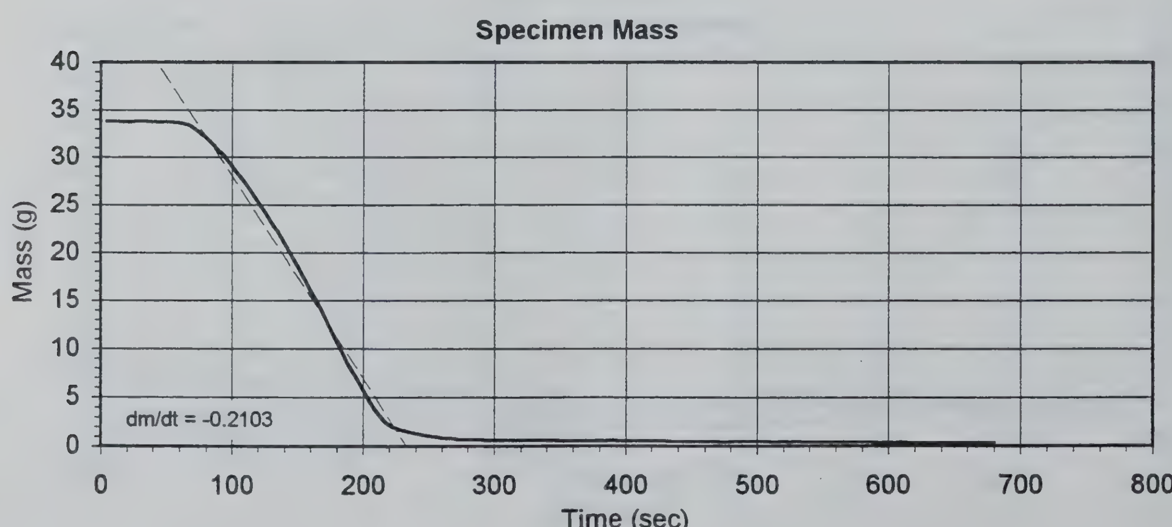


Cone Calorimeter Data R 4.06 Acrylic Glazing

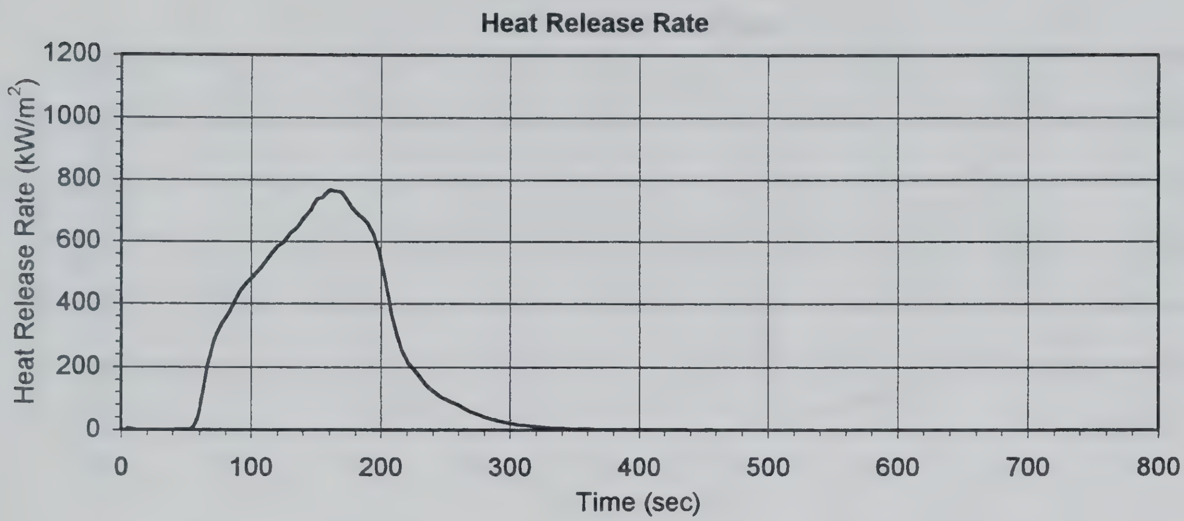
35 kW/m^2, Test #4

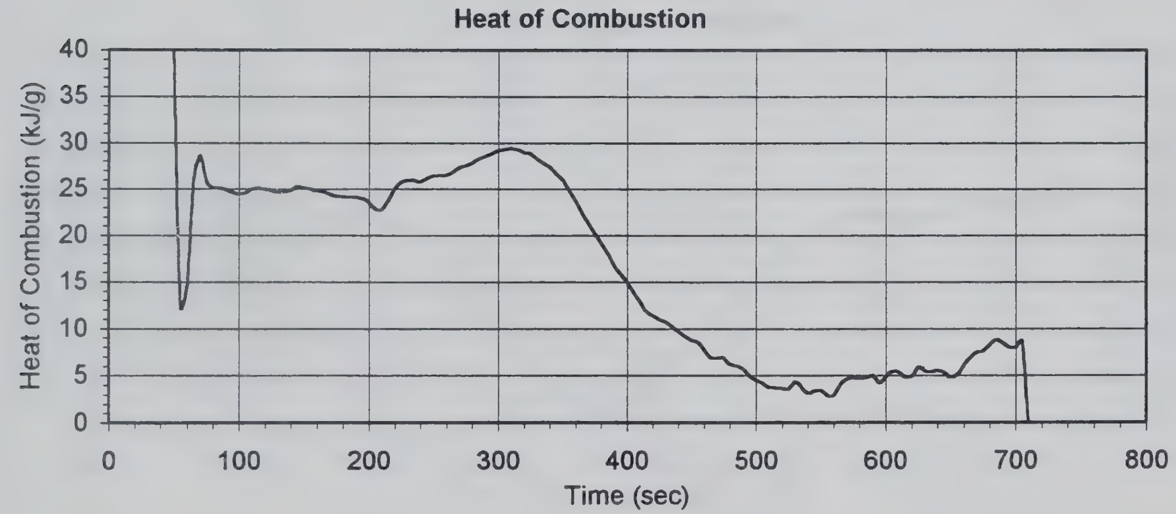


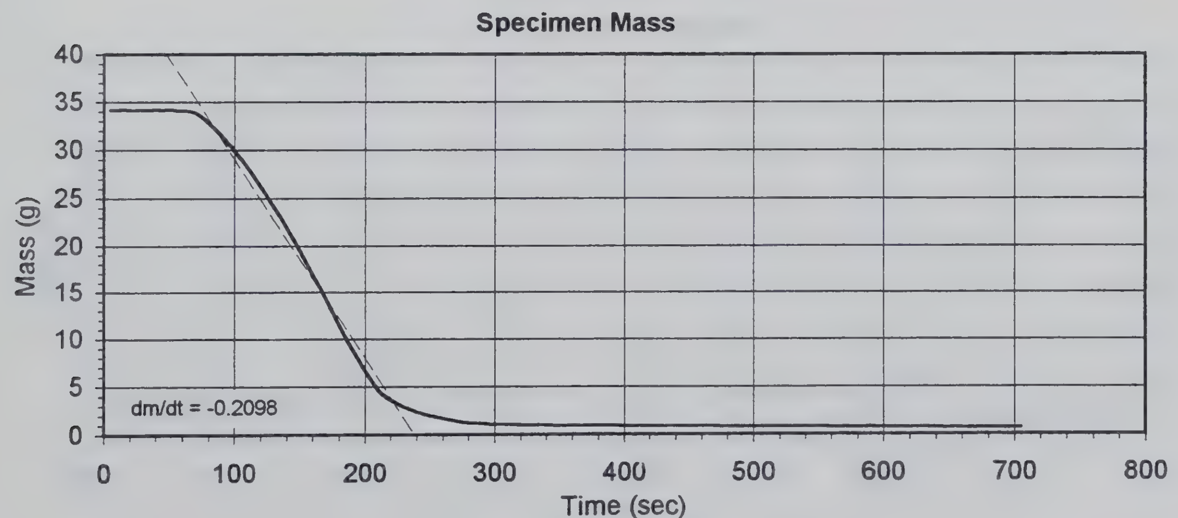




Cone Calorimeter Data R 4.06 Acrylic Glazing
35 kW/m^2, Test #5

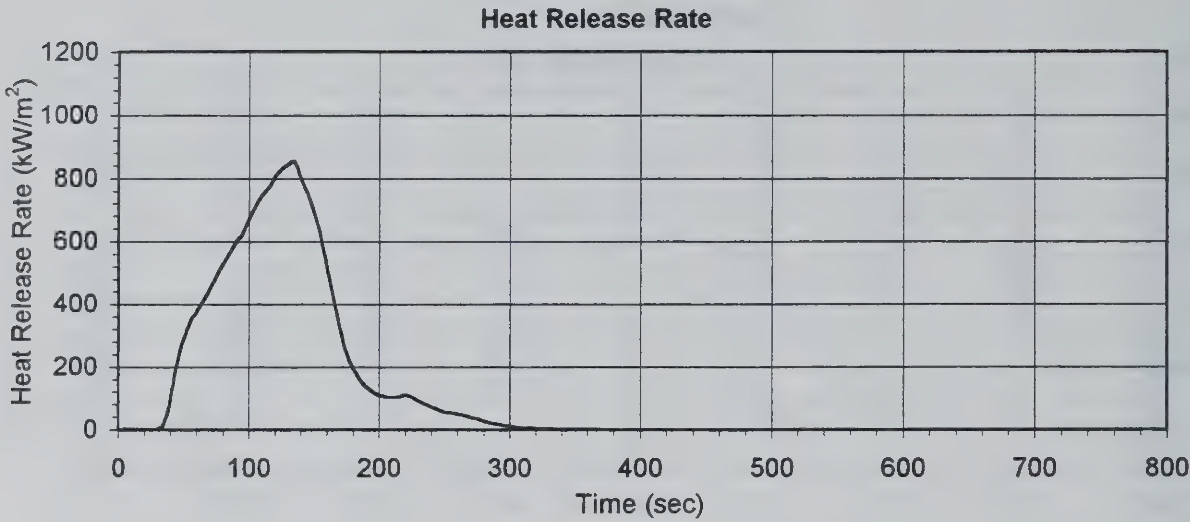


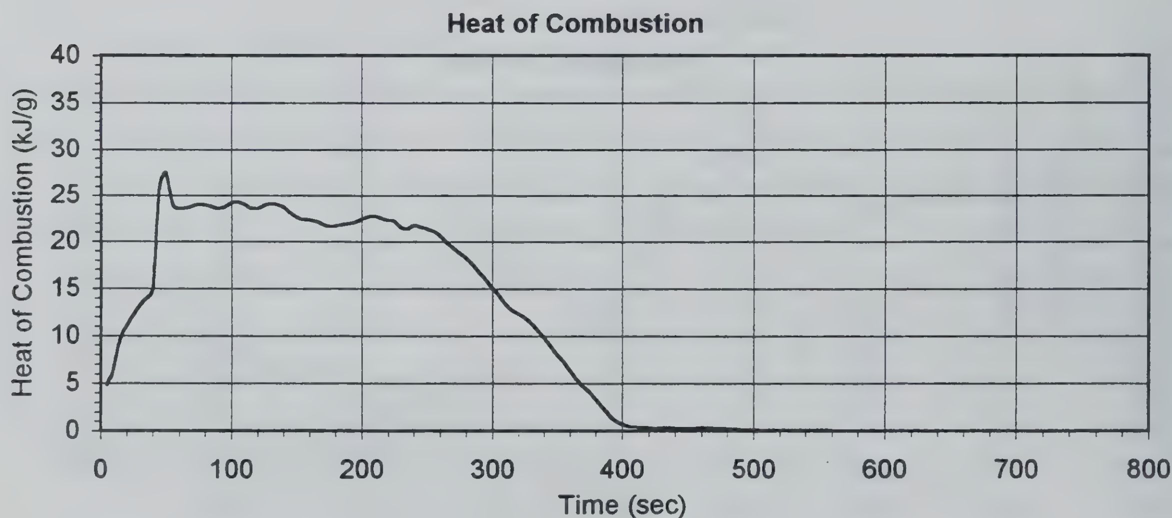


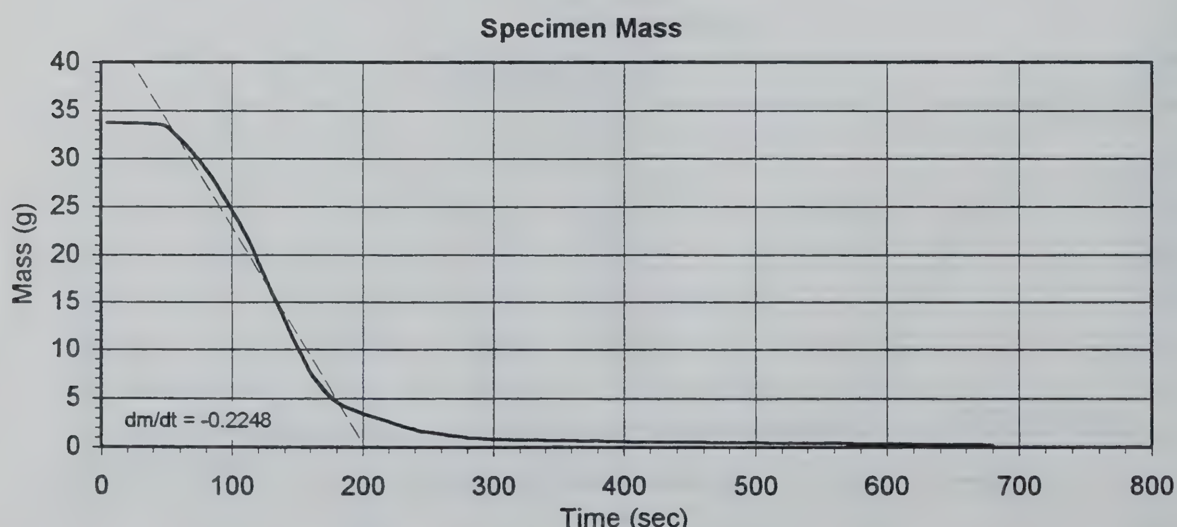


Cone Calorimeter Data R 4.06 Acrylic Glazing

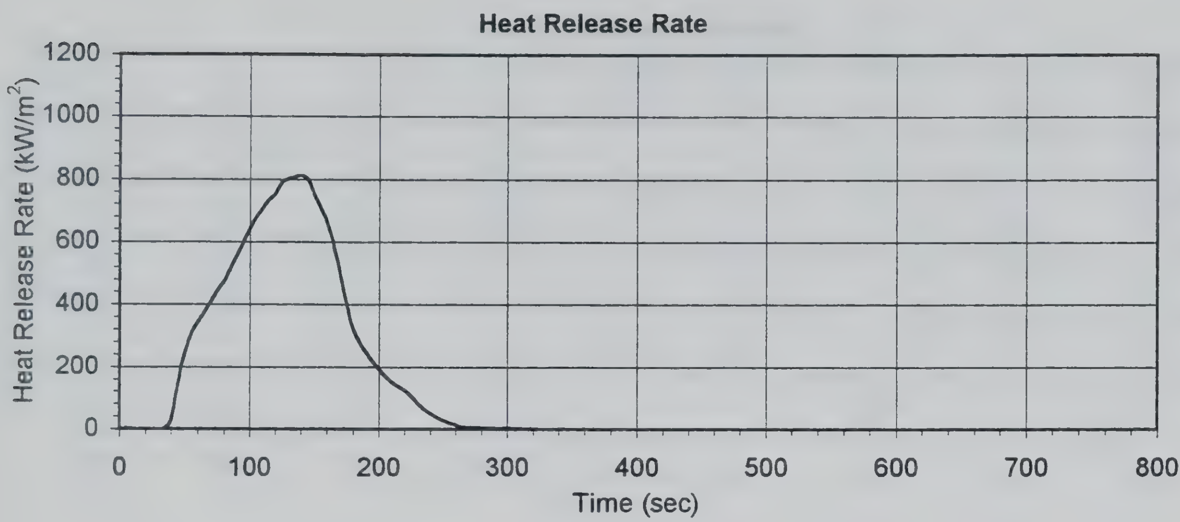
40 kW/m^2, Test #1

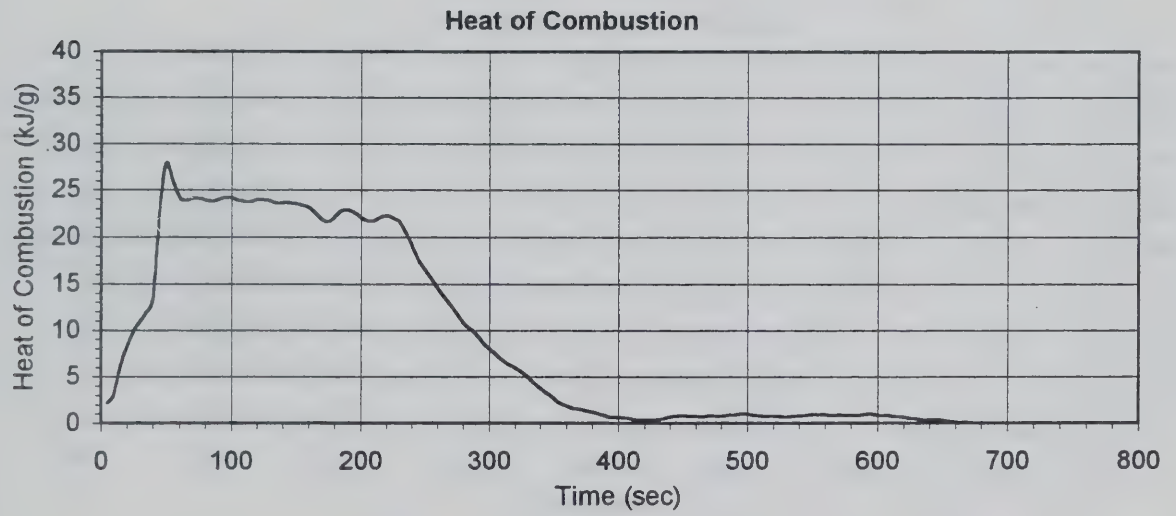


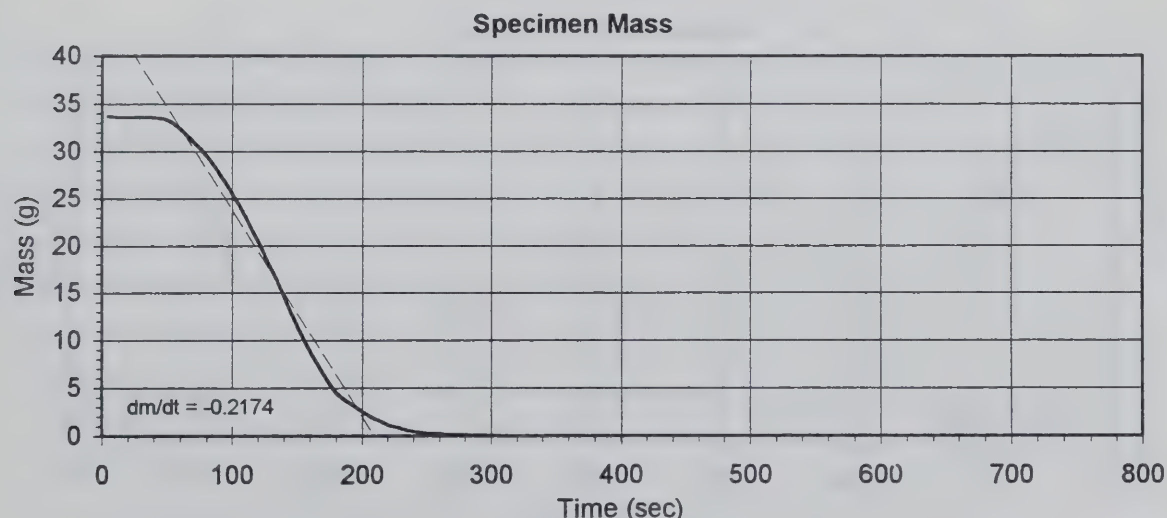




Cone Calorimeter Data R 4.06 Acrylic Glazing
40 kW/m^2, Test #2







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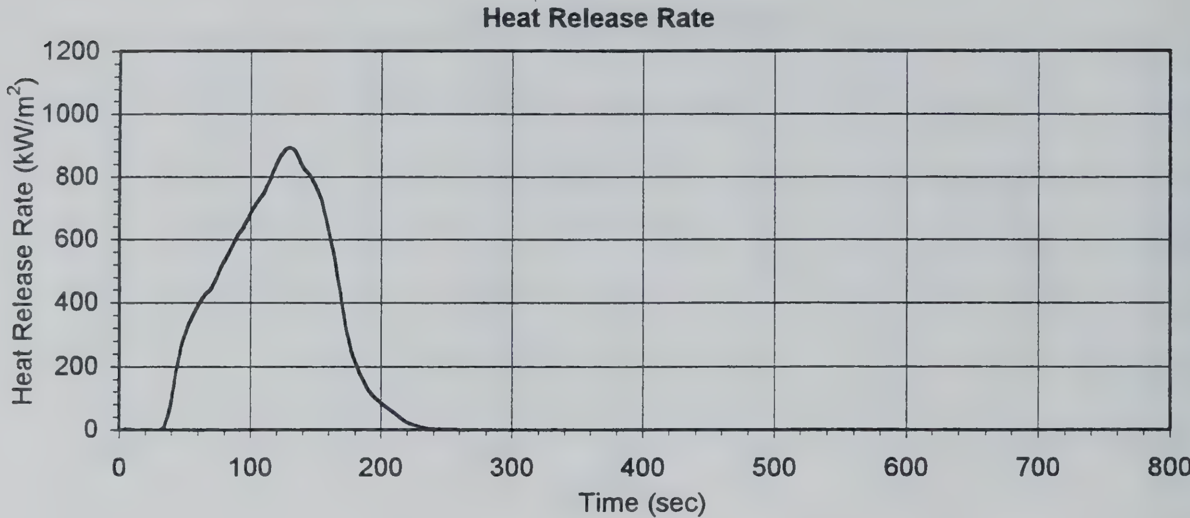
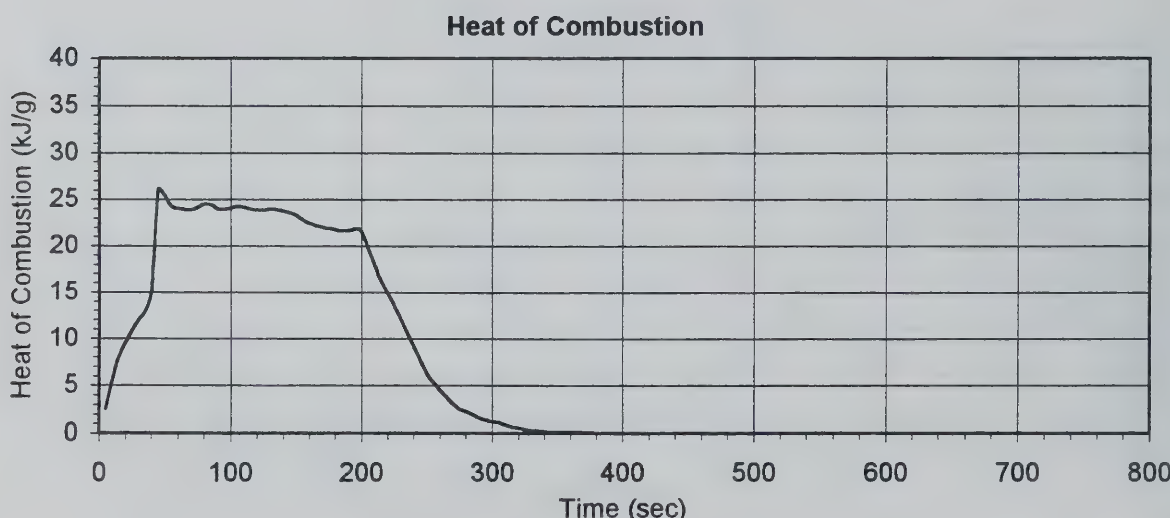
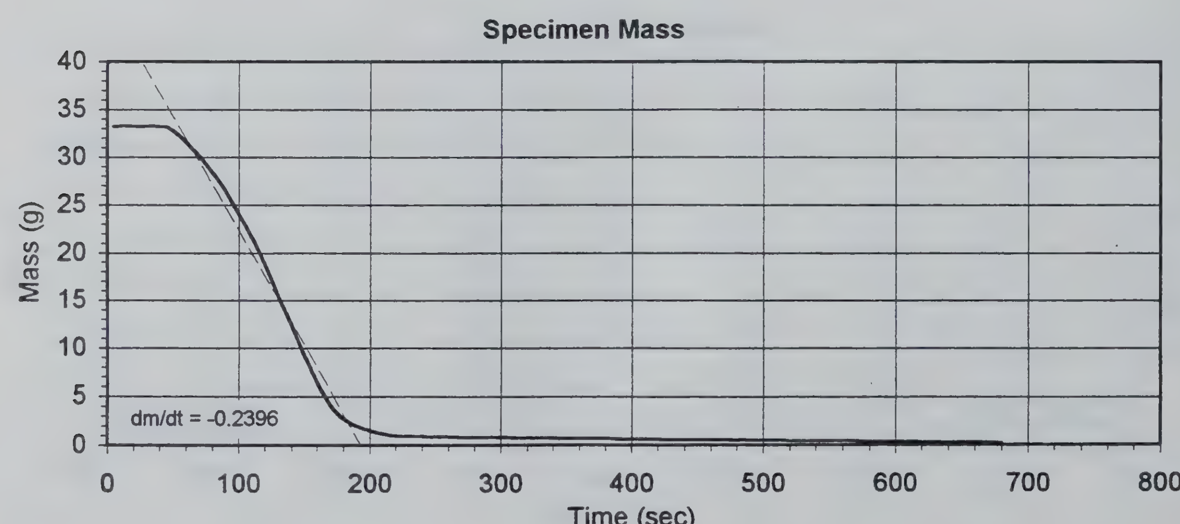
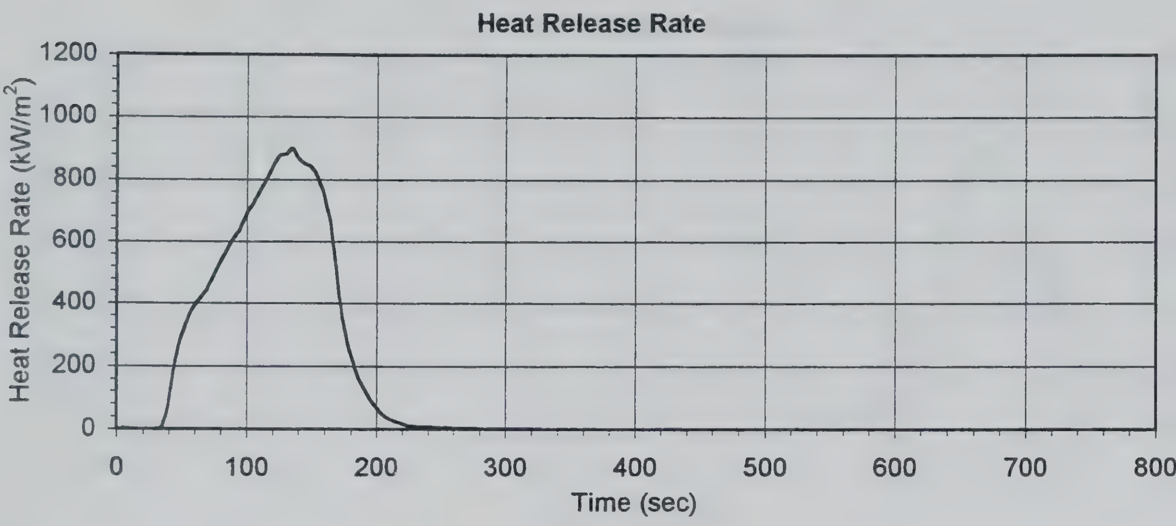


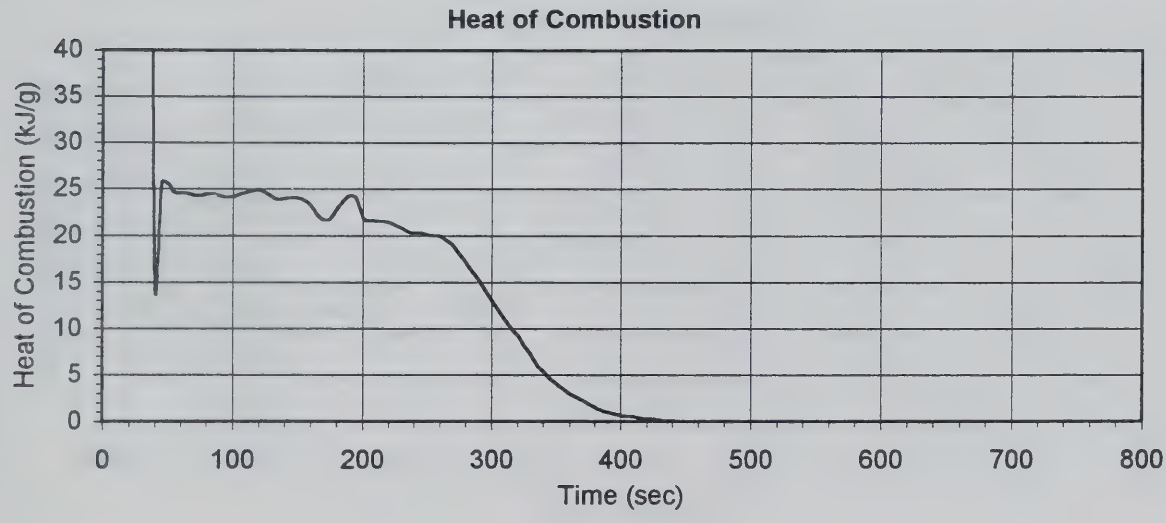


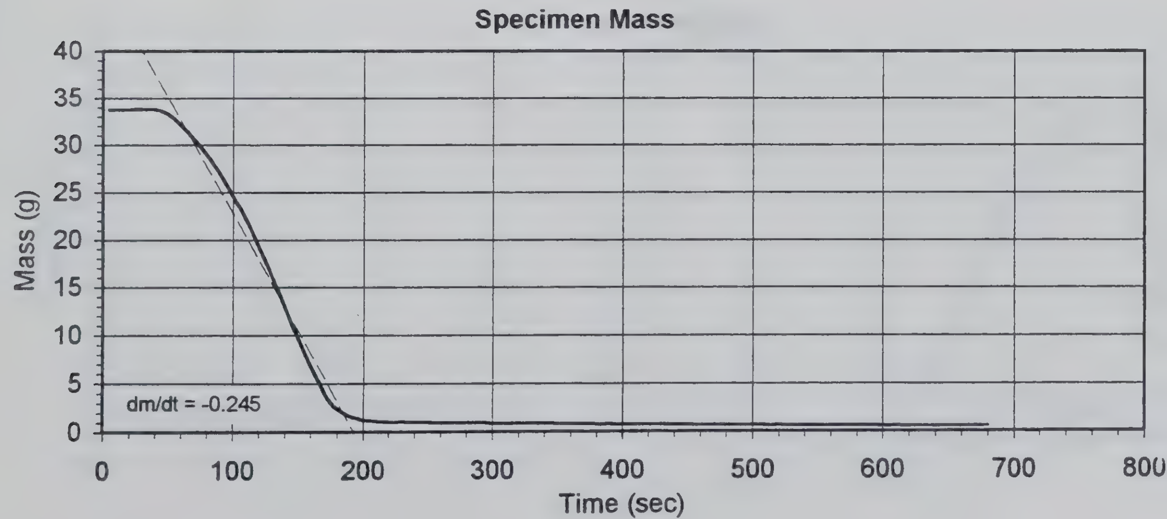


Cone Calorimeter Data R 4.06 Acrylic Glazing

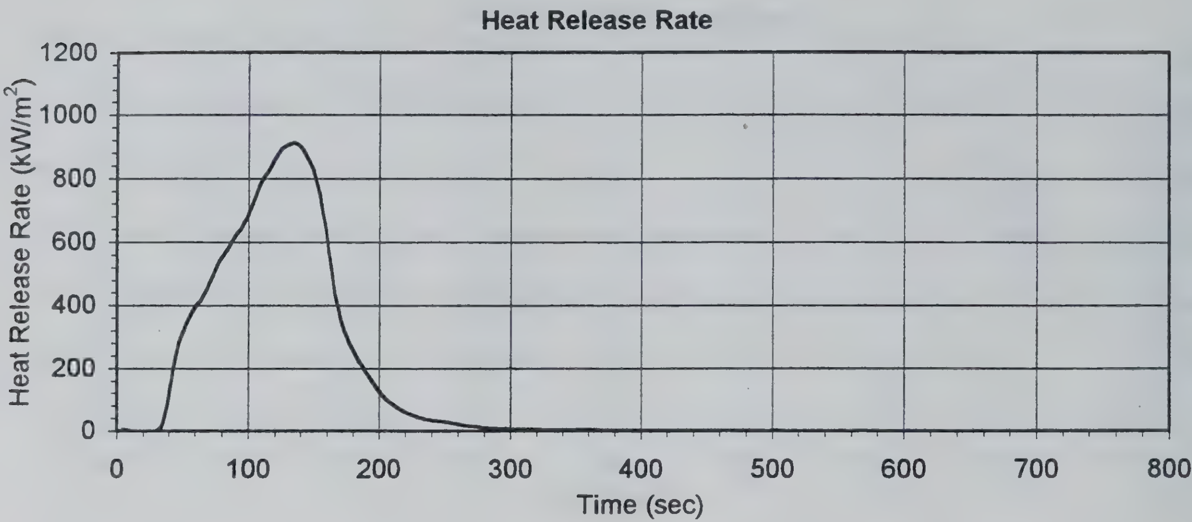
40 kW/m^2, Test #4

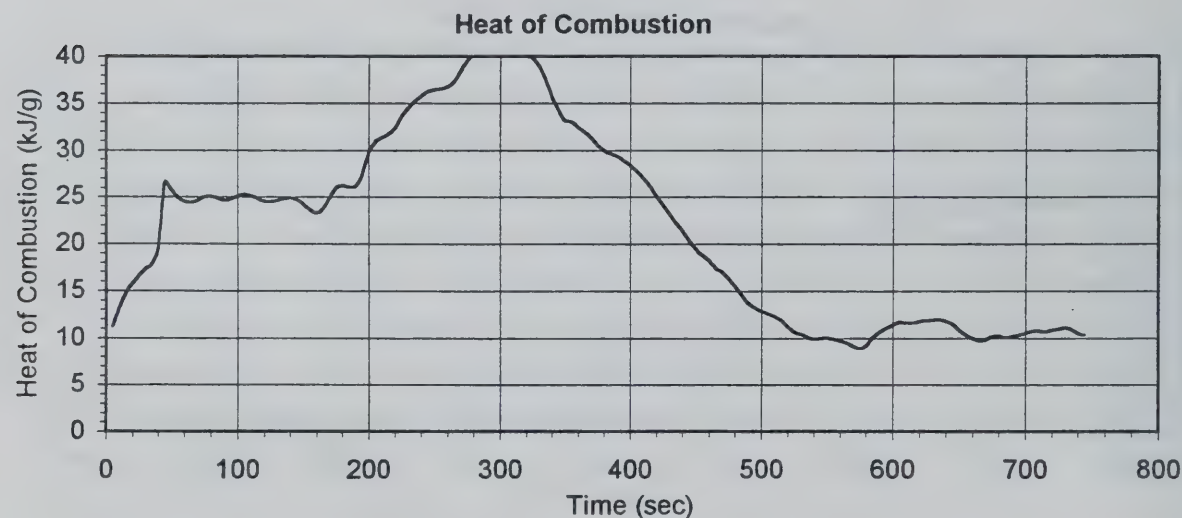


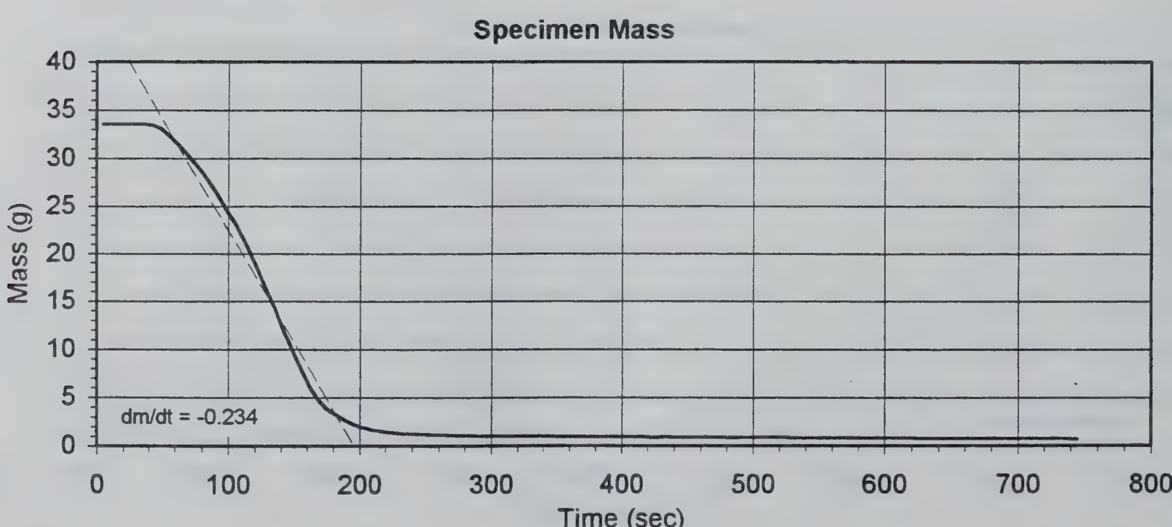




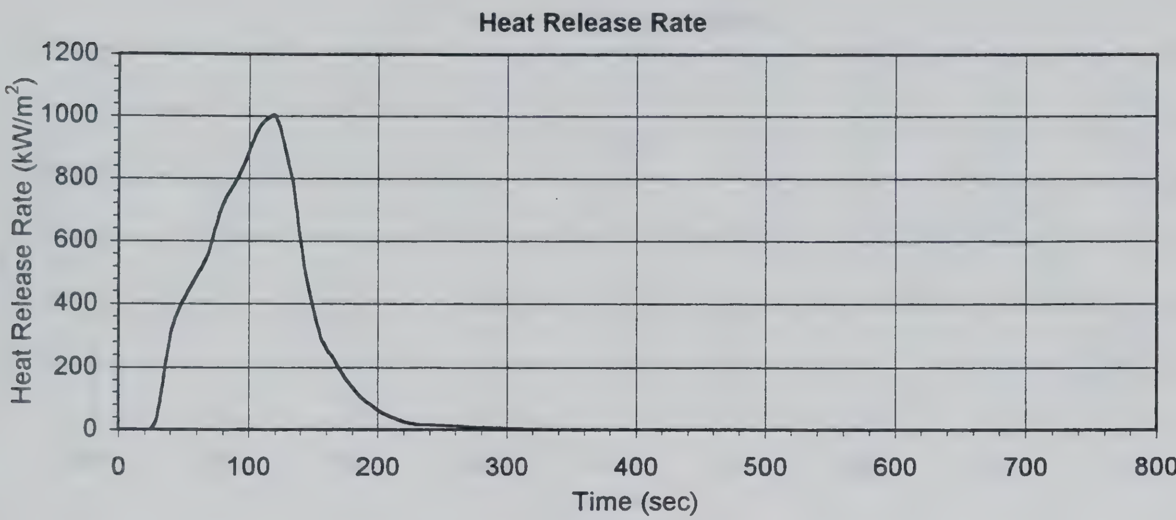
Cone Calorimeter Data R 4.06 Acrylic Glazing
40 kW/m^2, Test #5

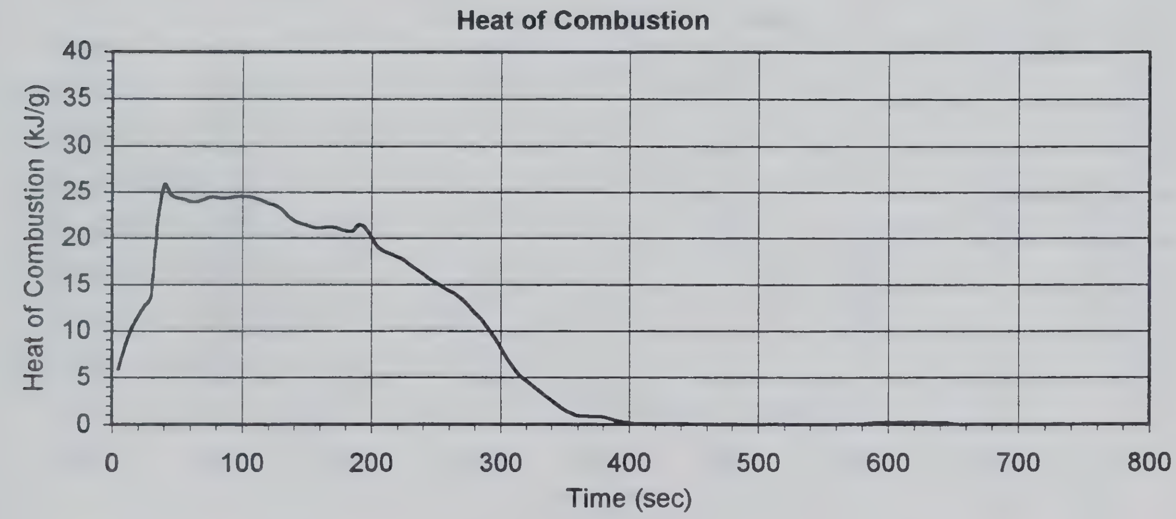


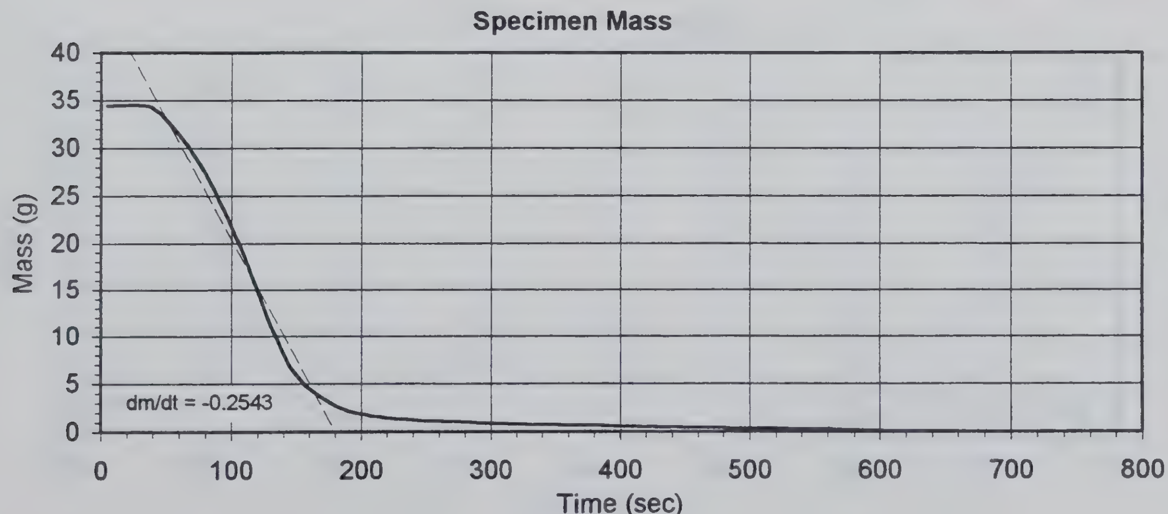




Cone Calorimeter Data R 4.06 Acrylic Glazing
50 kW/m^2, Test #1







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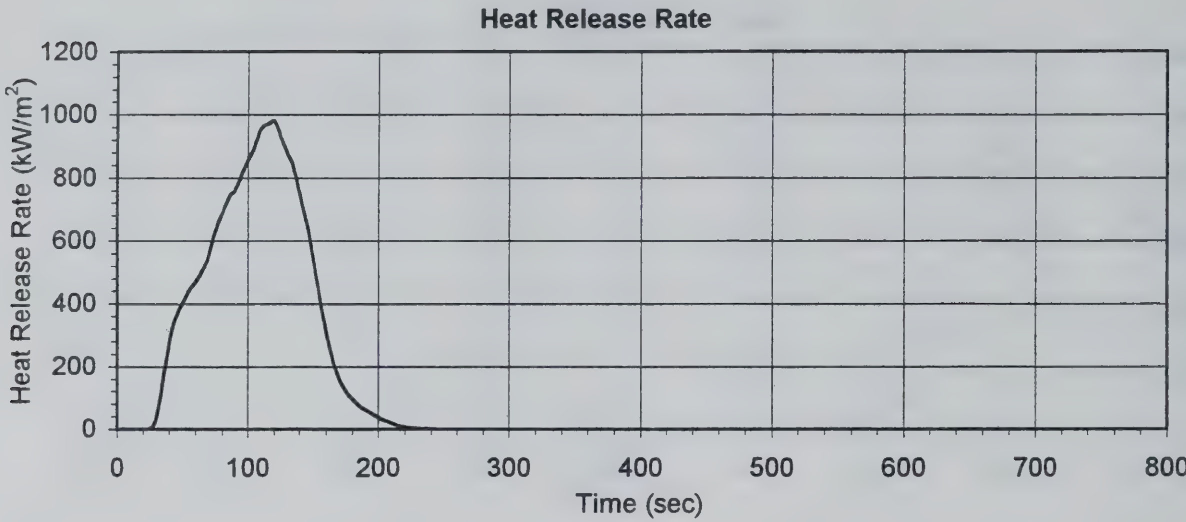
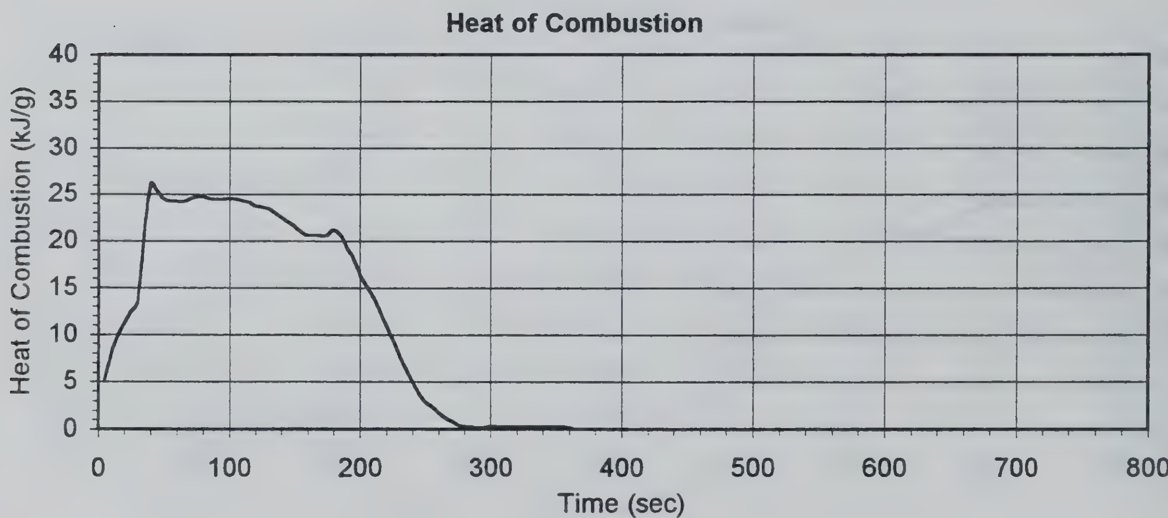
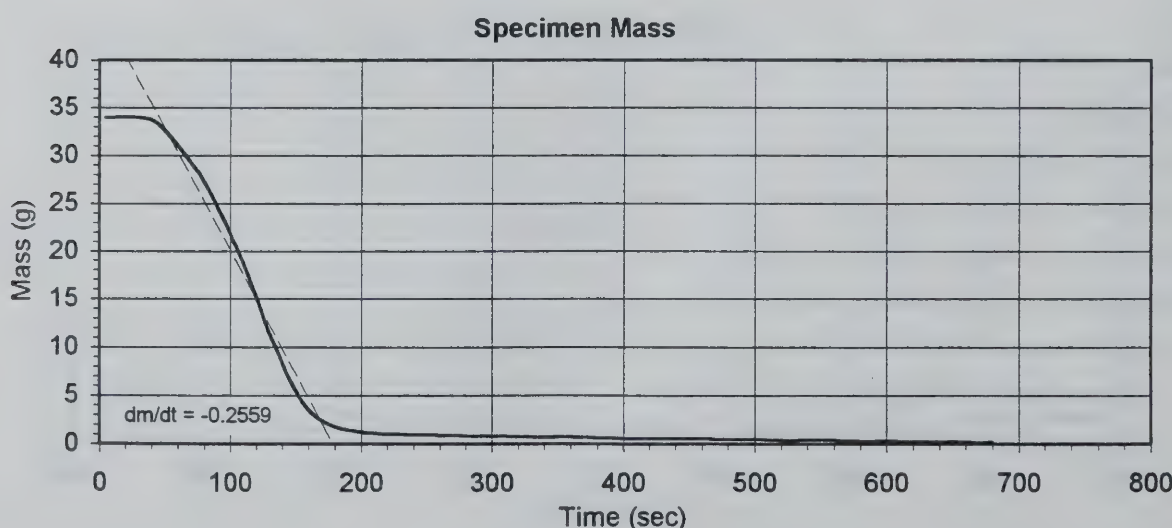
50 kW/m^2, Test #2







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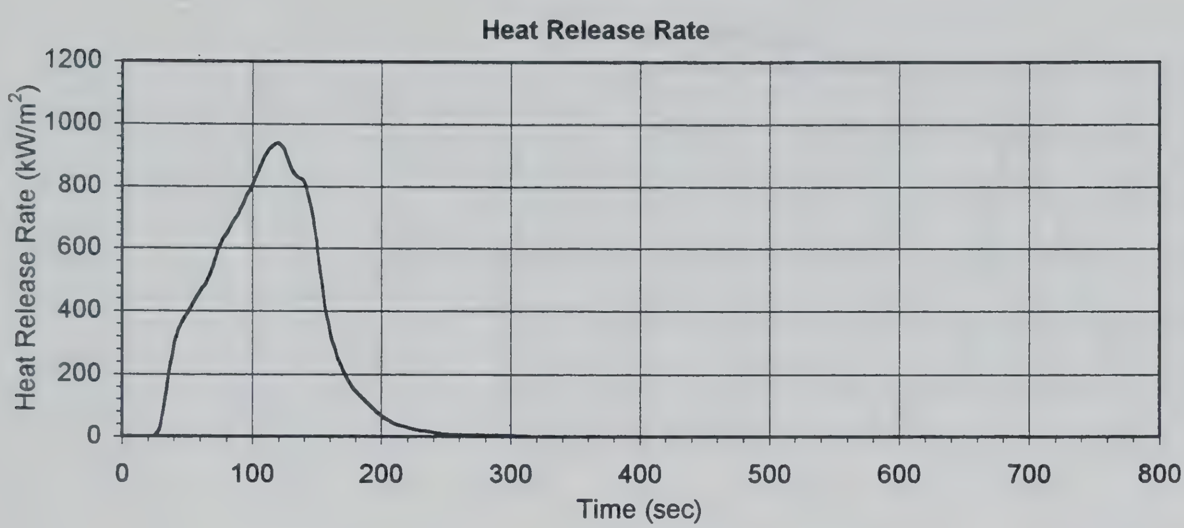

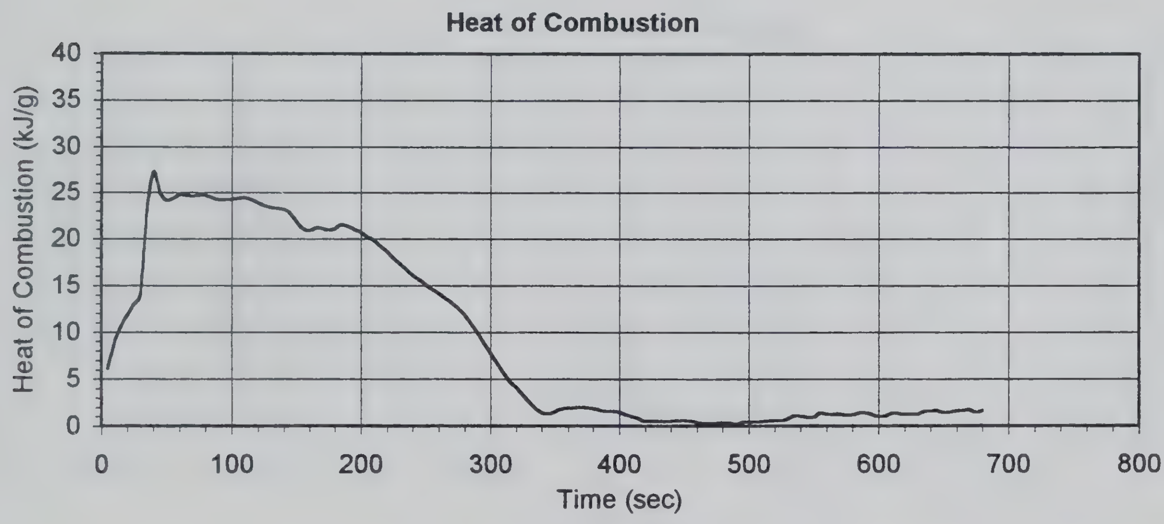

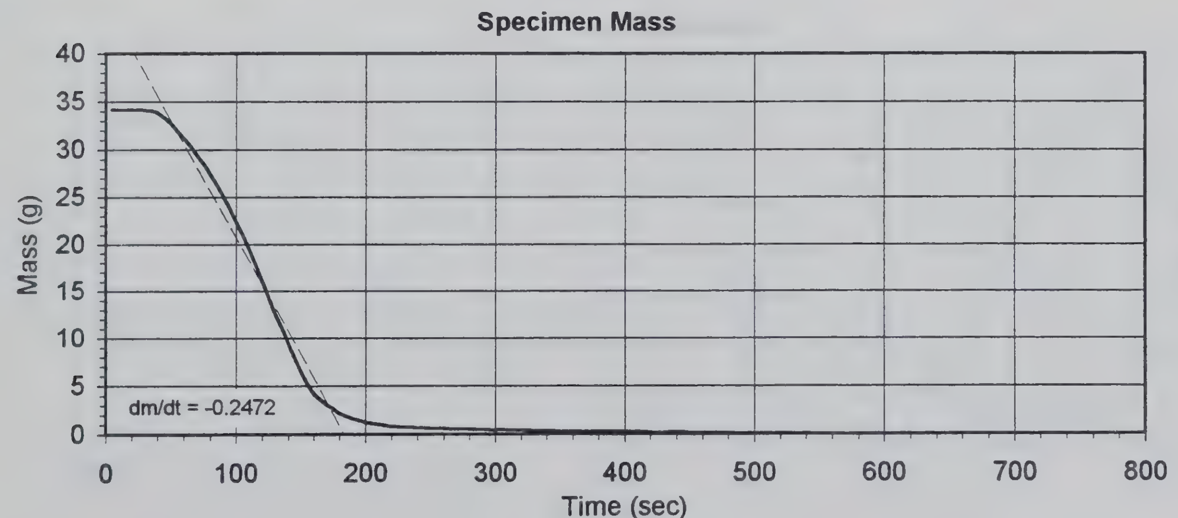

Cone Calorimeter Data R 4.06 Acrylic Glazing
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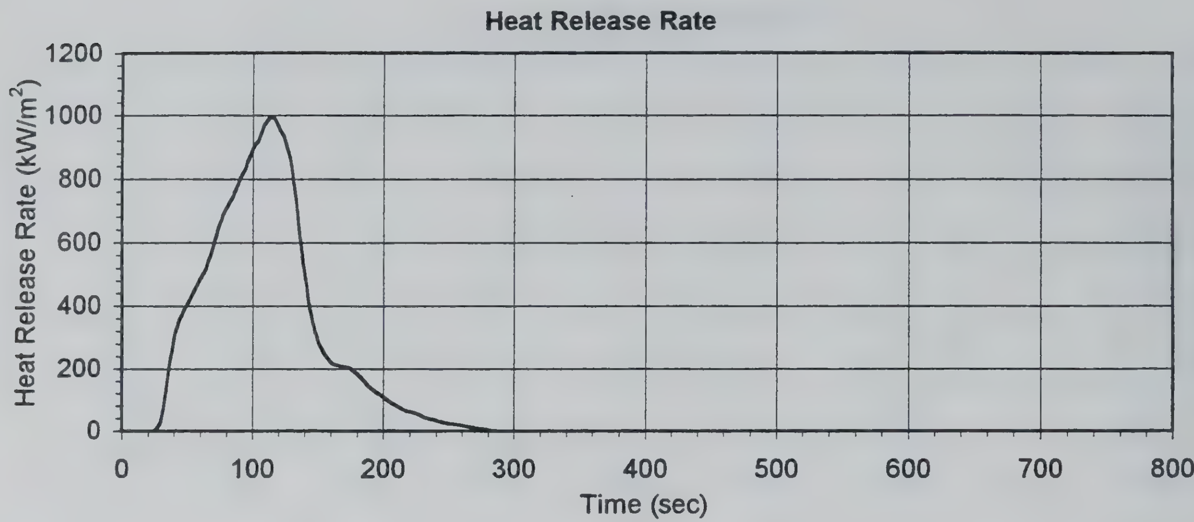
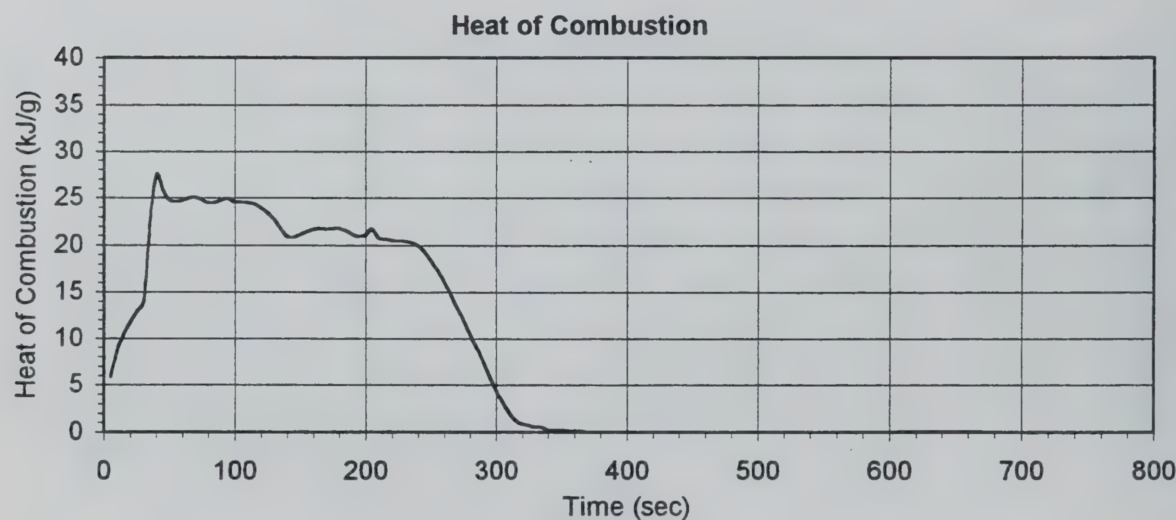
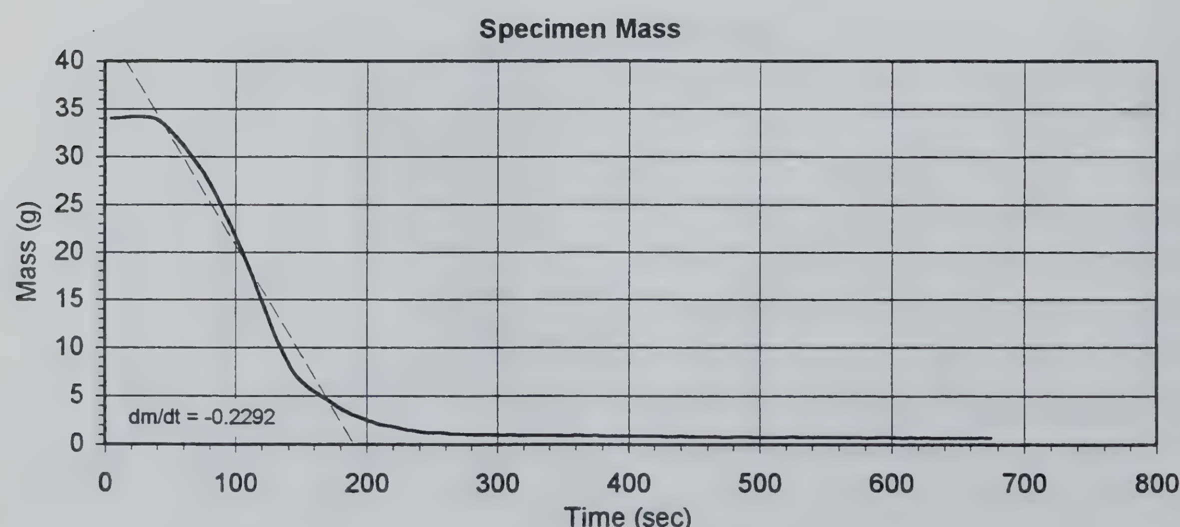
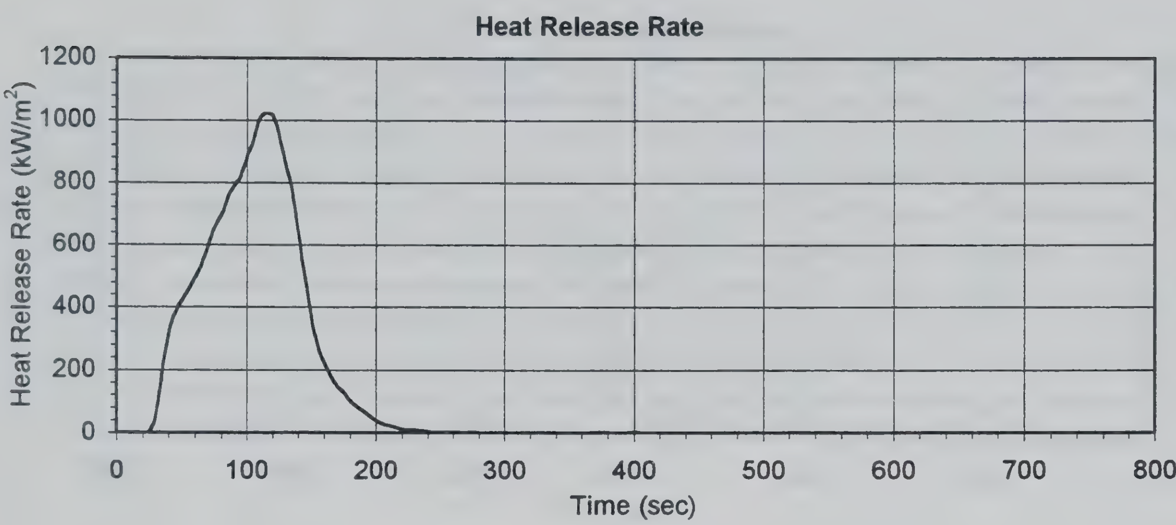
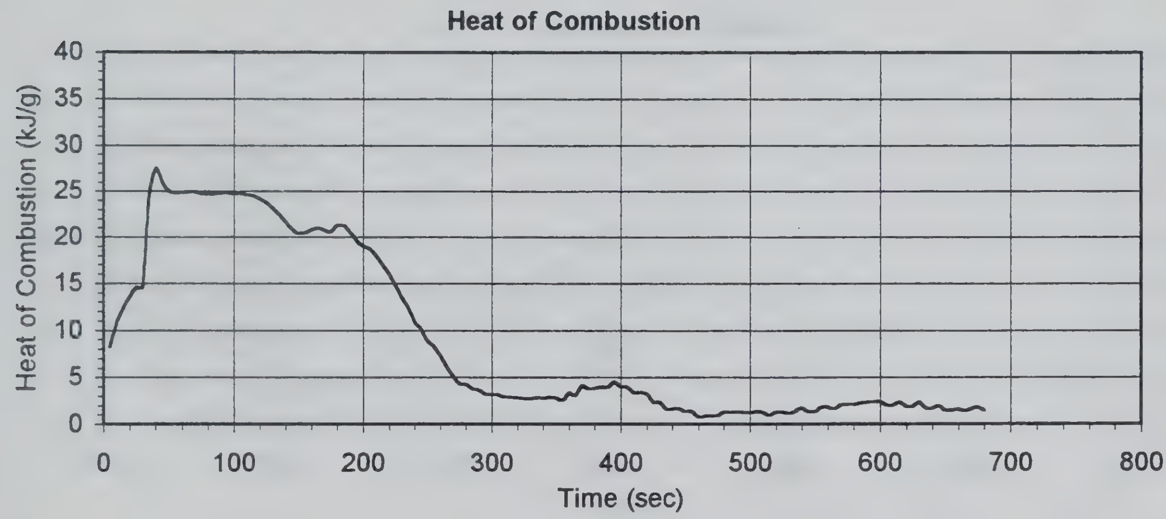


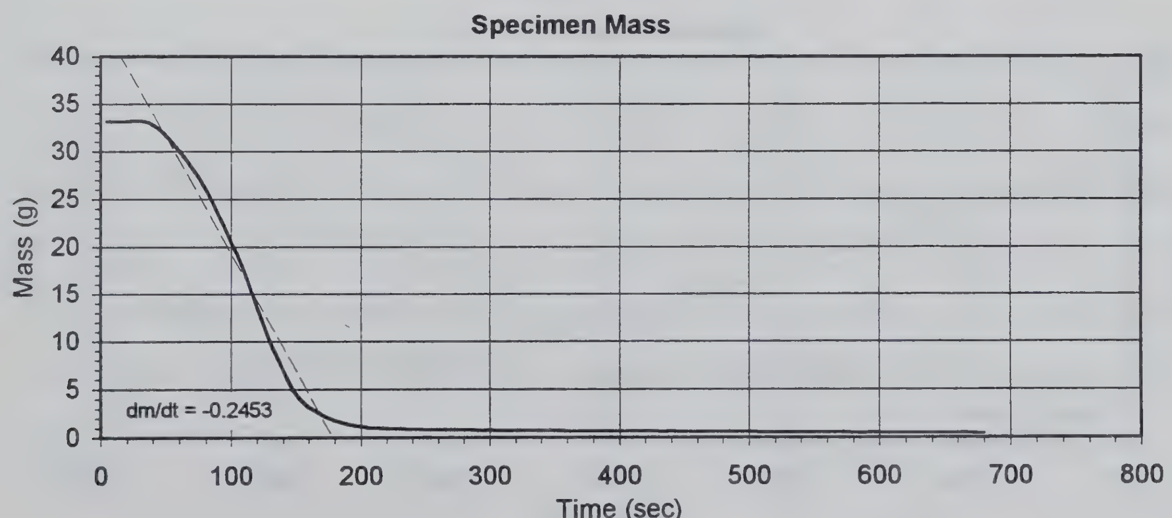




Cone Calorimeter Data R 4.06 Acrylic Glazing
50 kW/m^2, Test #5

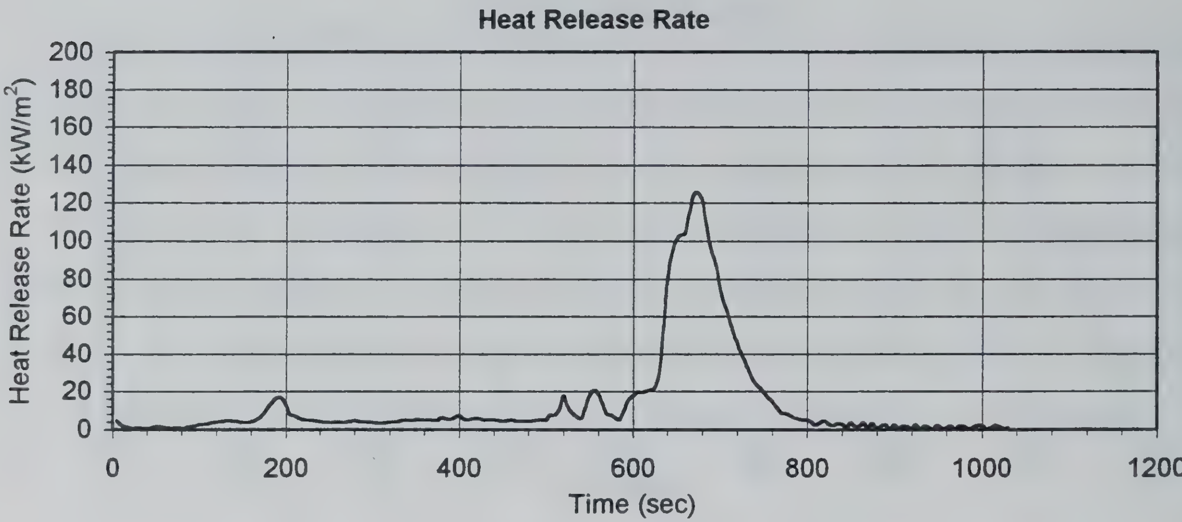


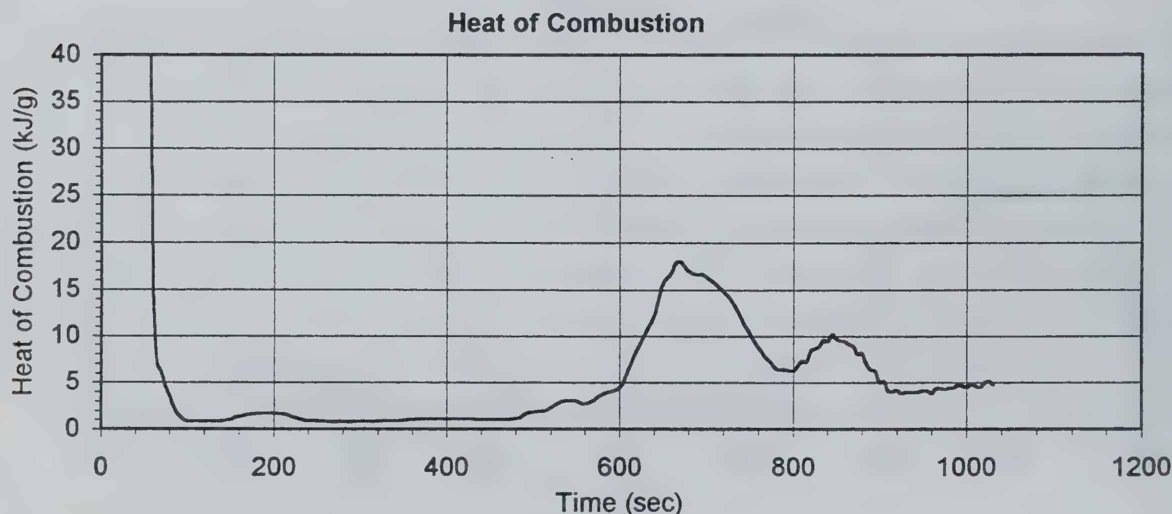


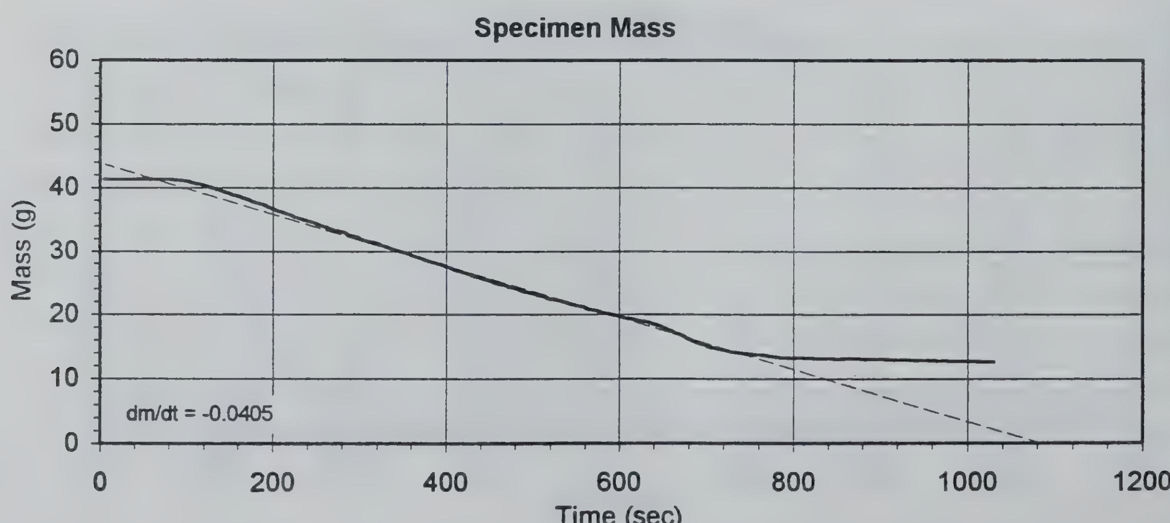


Cone Calorimeter Data R 4.07 F.R. PVC

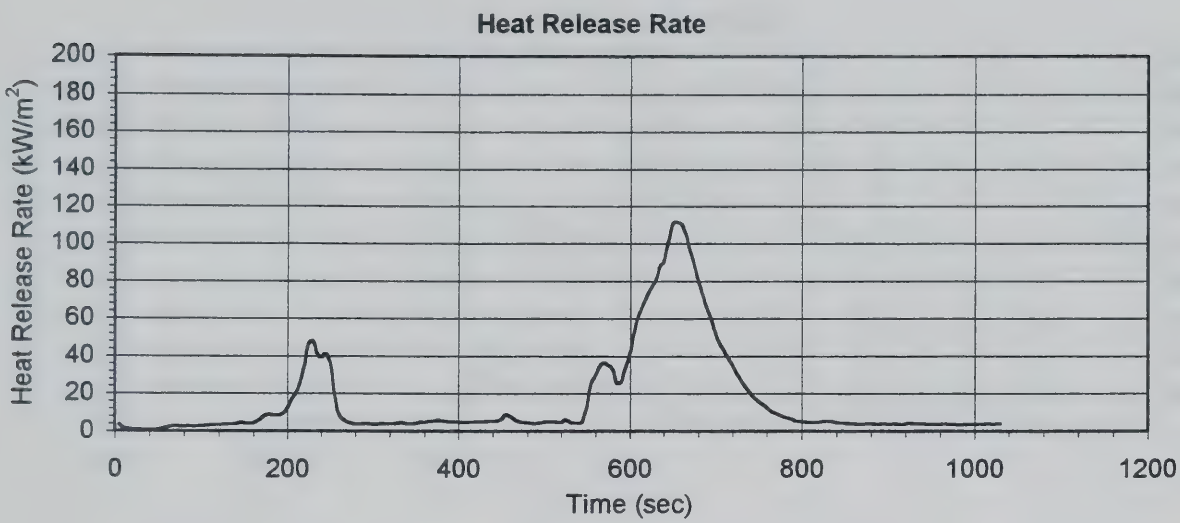
25 kW/m^2, Test #1

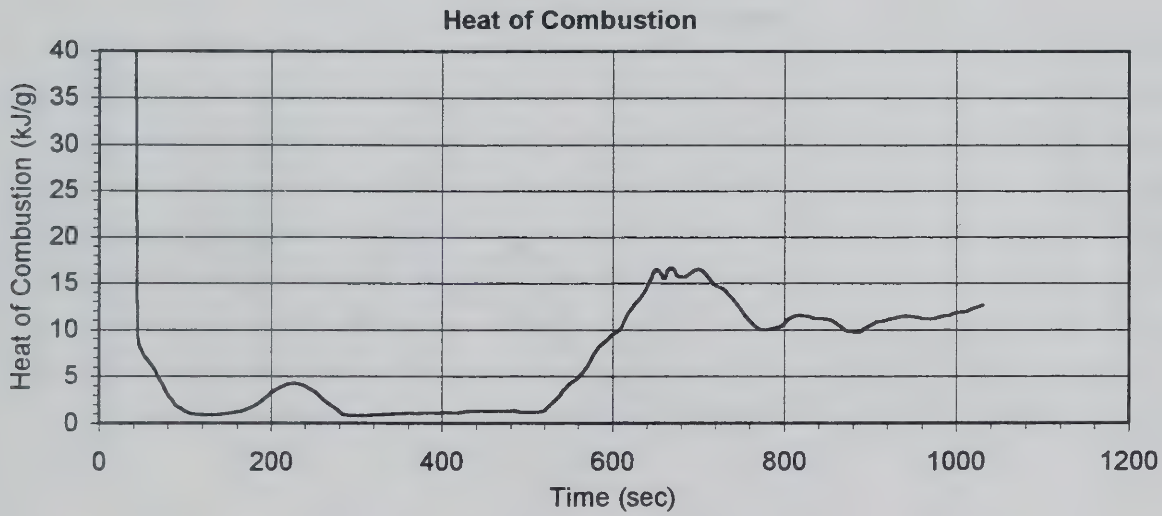


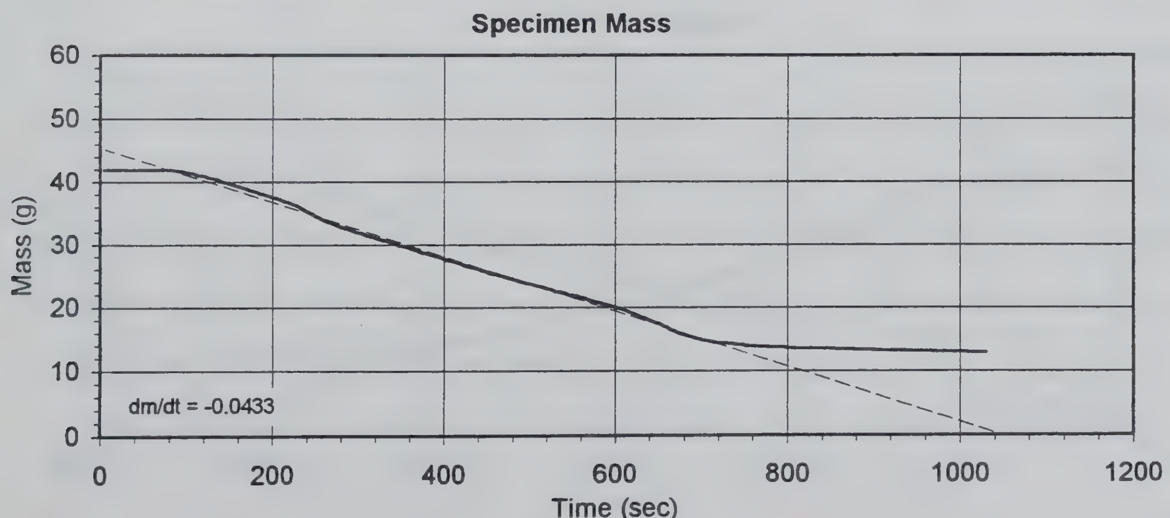




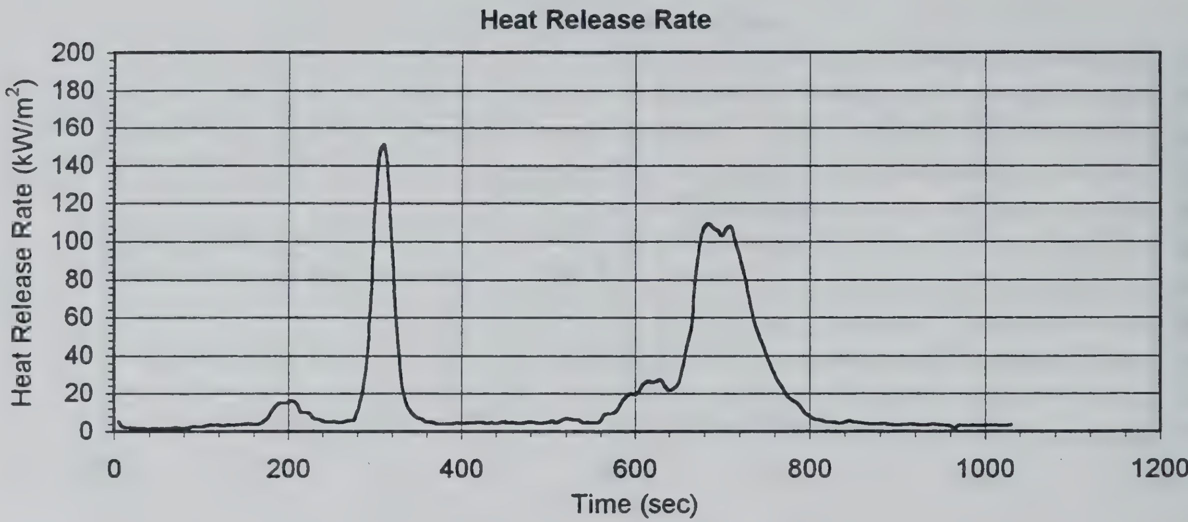
Cone Calorimeter Data R 4.07 F.R. PVC
25 kW/m², Test #2

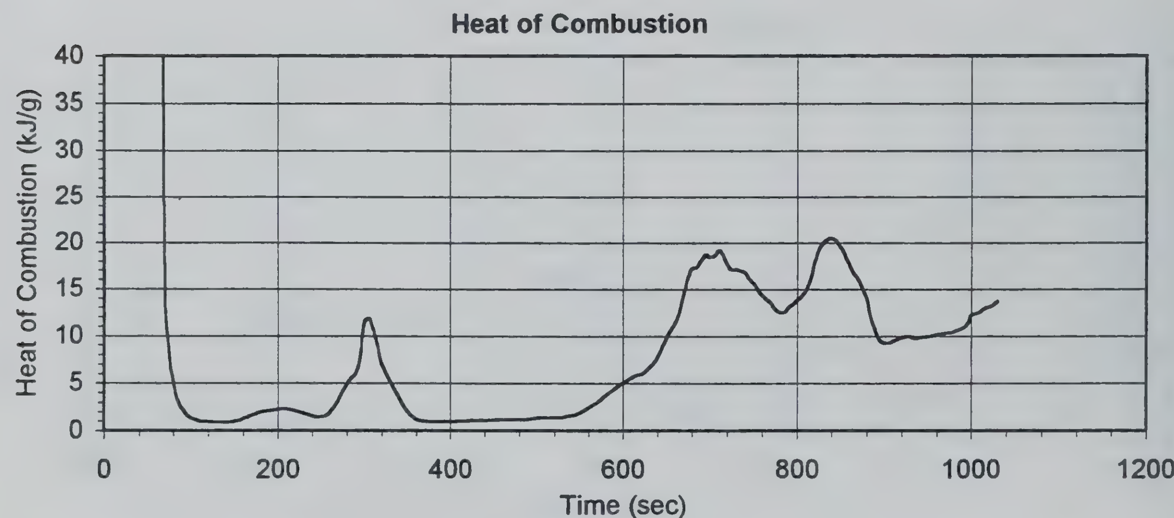


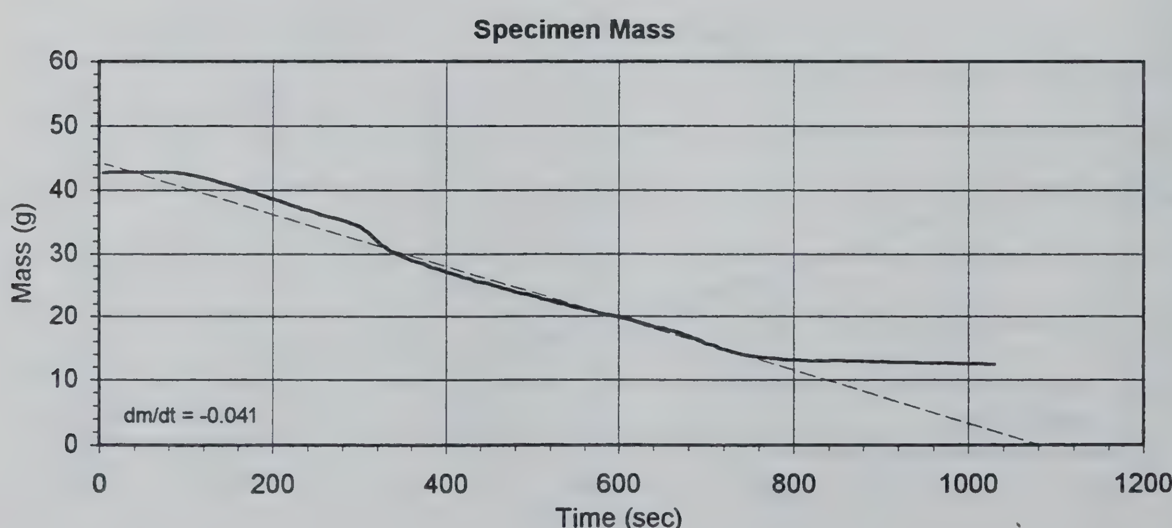




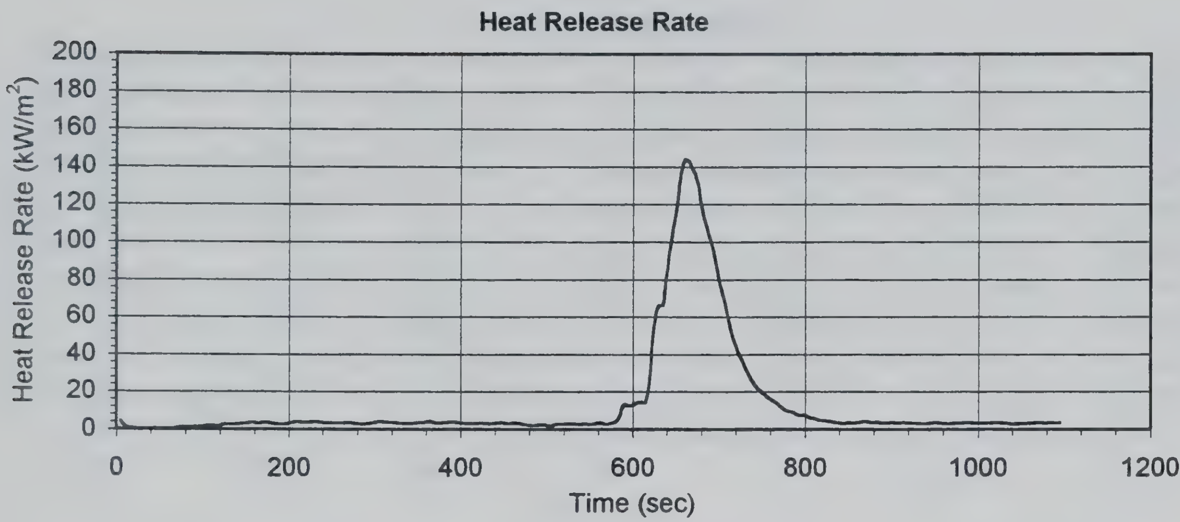
Cone Calorimeter Data R 4.07 F.R. PVC
25 kW/m², Test #4

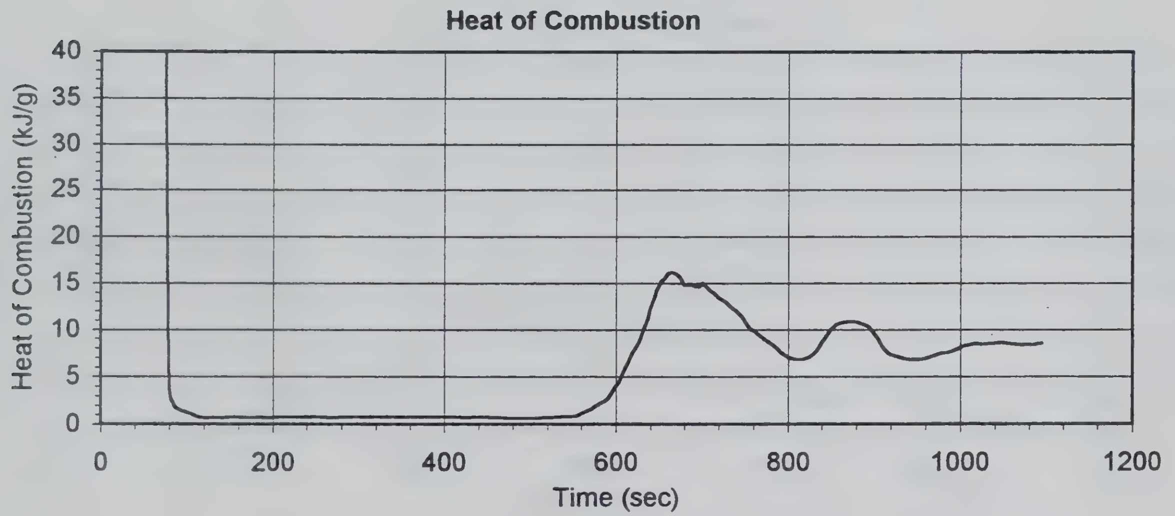


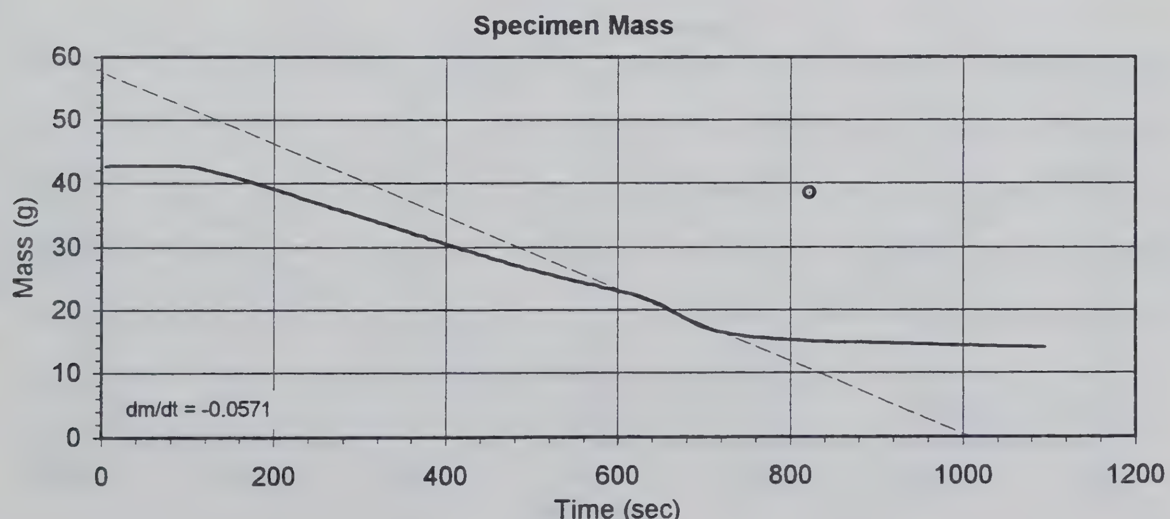




Cone Calorimeter Data R 4.07 F.R. PVC
25 kW/m^2, Test #5

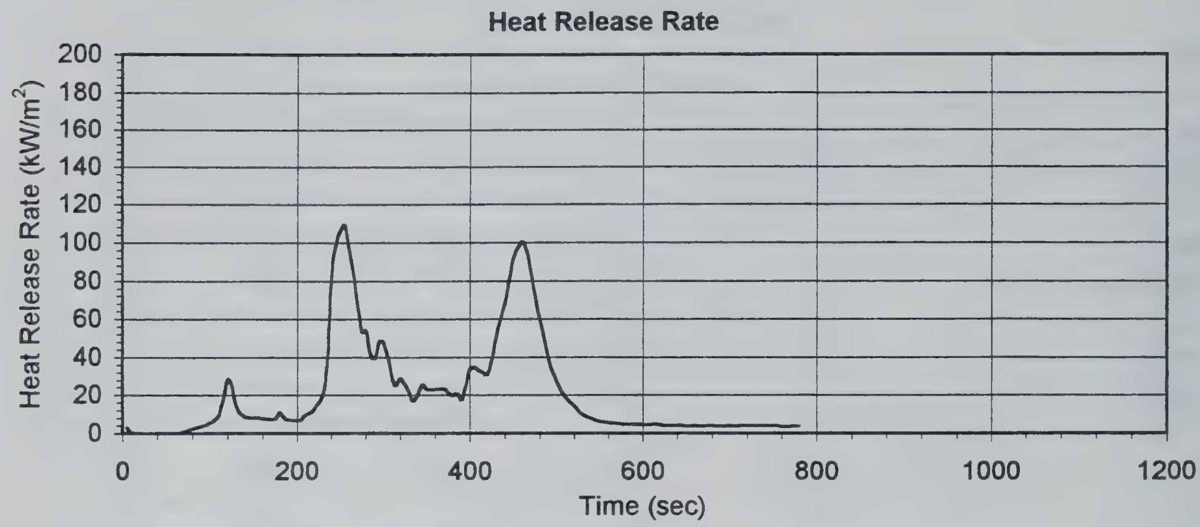


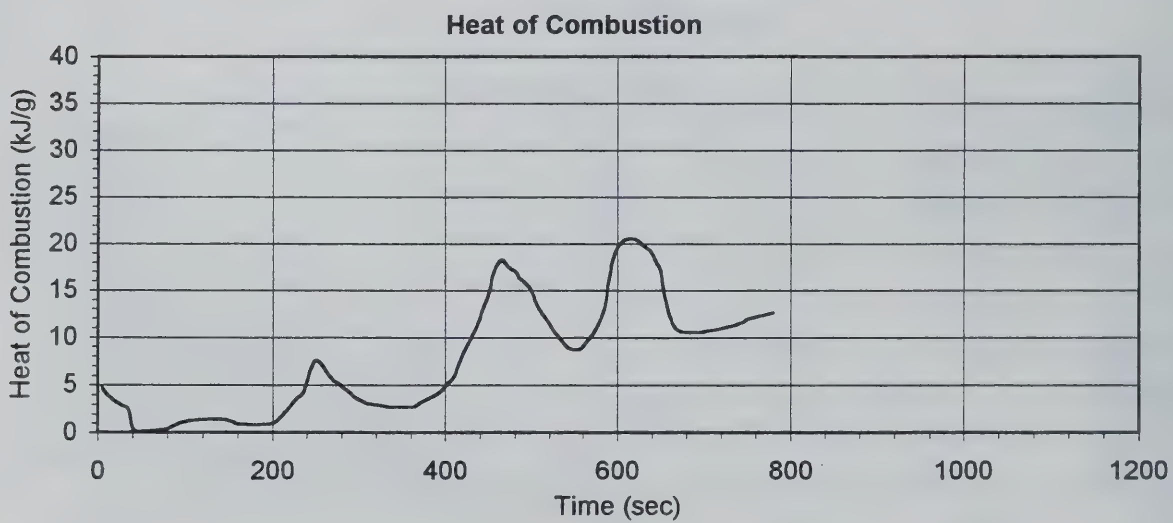


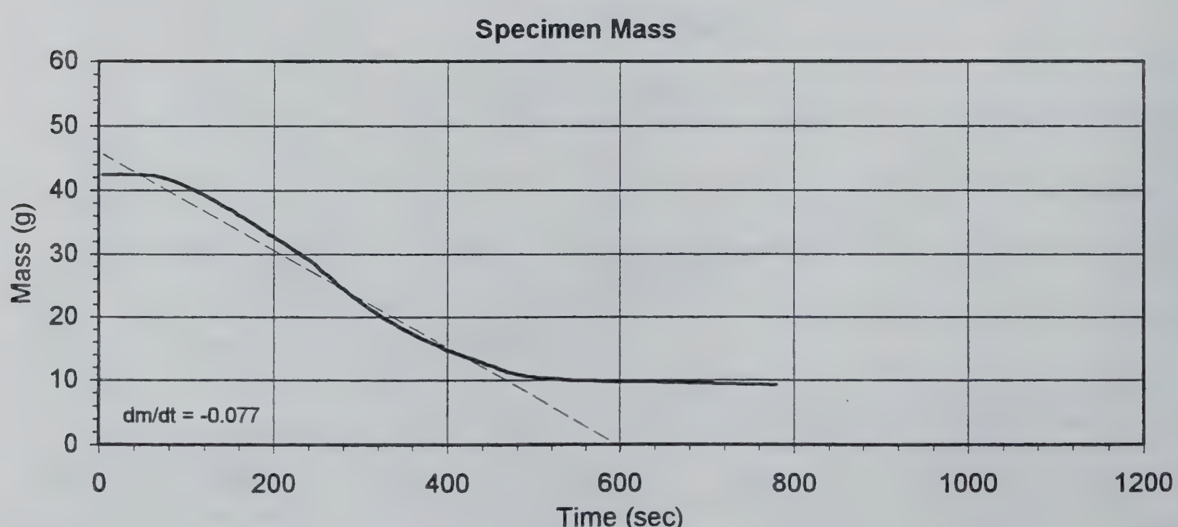


Cone Calorimeter Data R 4.07 F.R. PVC

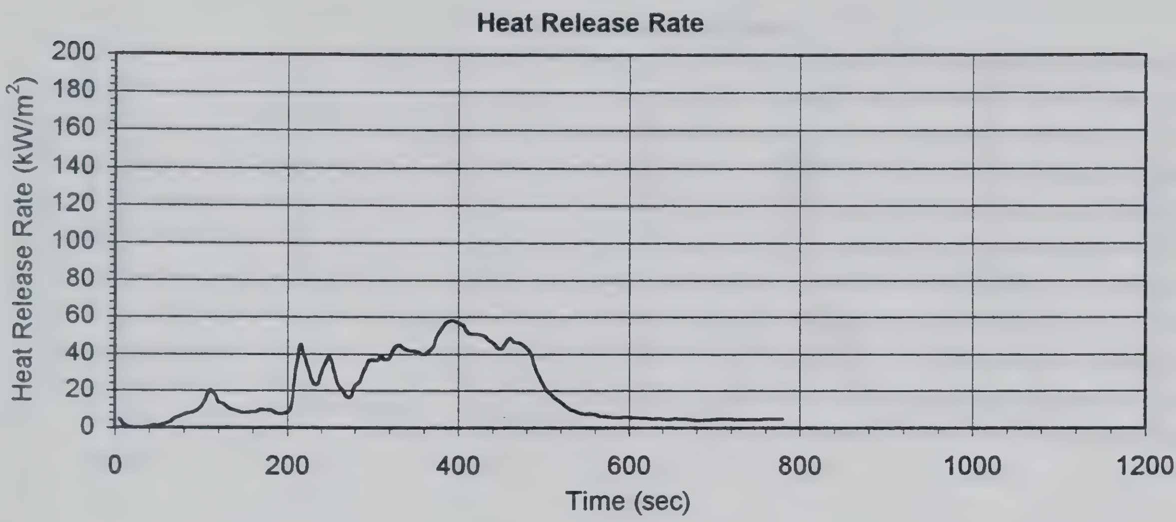
35 kW/m^2, Test #1

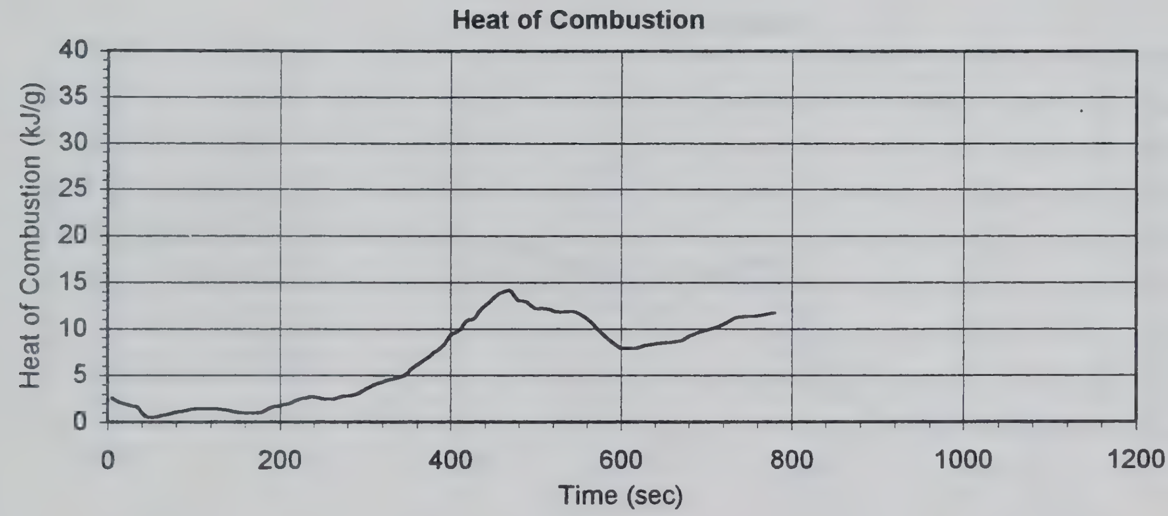


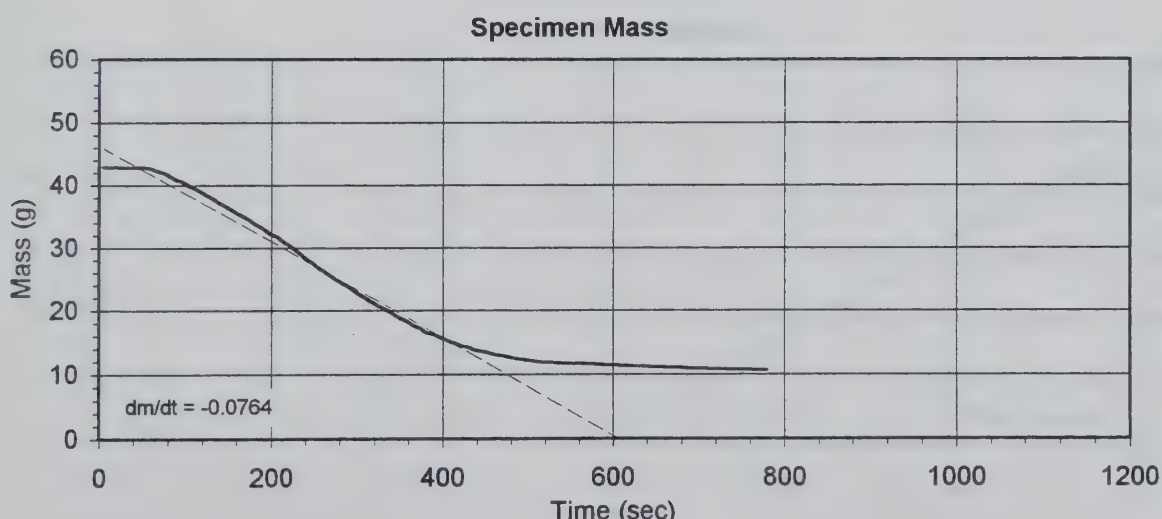




Cone Calorimeter Data R 4.07 F.R. PVC
35 kW/m^2, Test #2

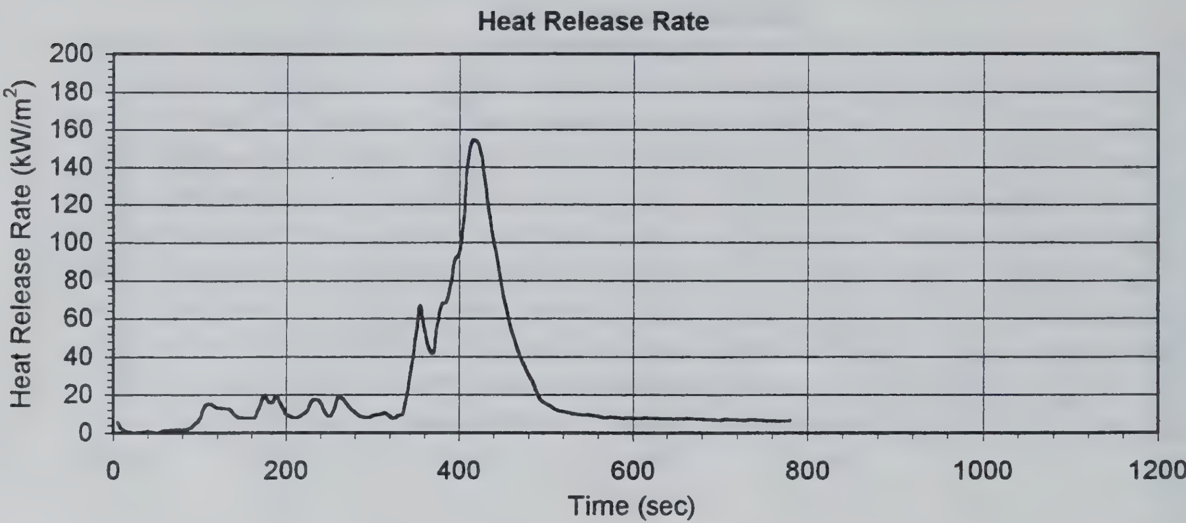


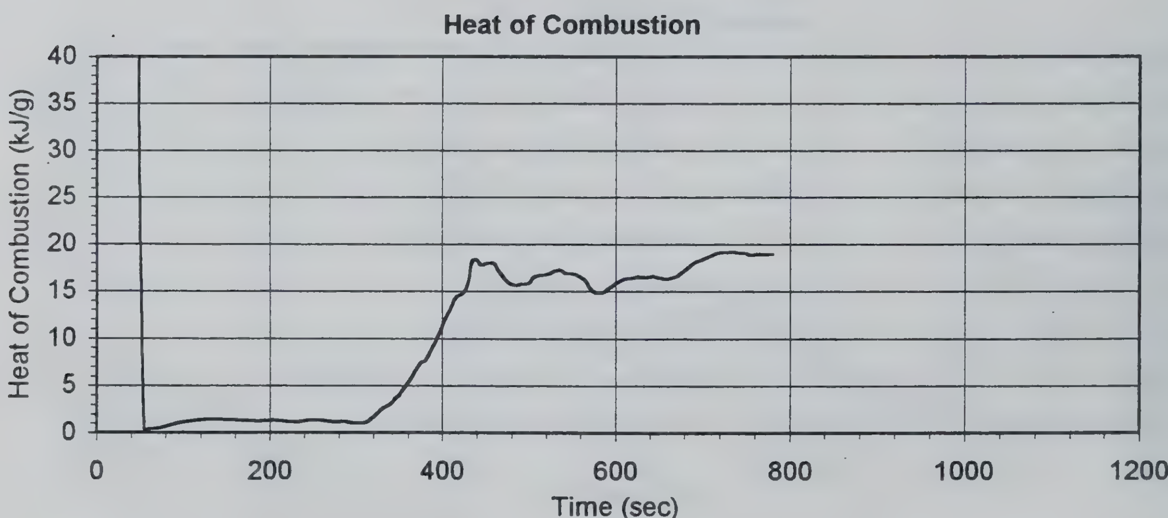


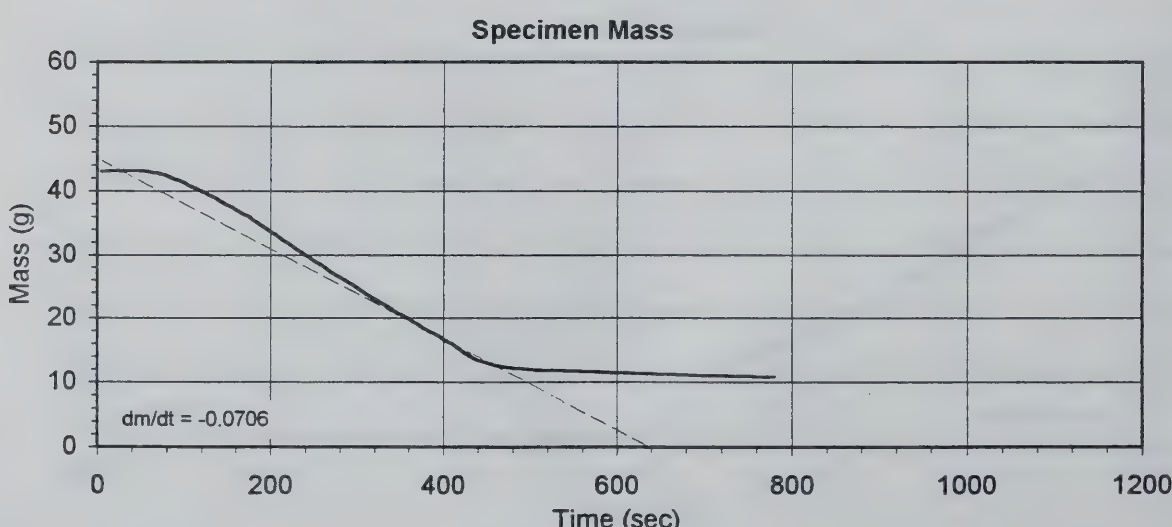


Cone Calorimeter Data R 4.07 F.R. PVC

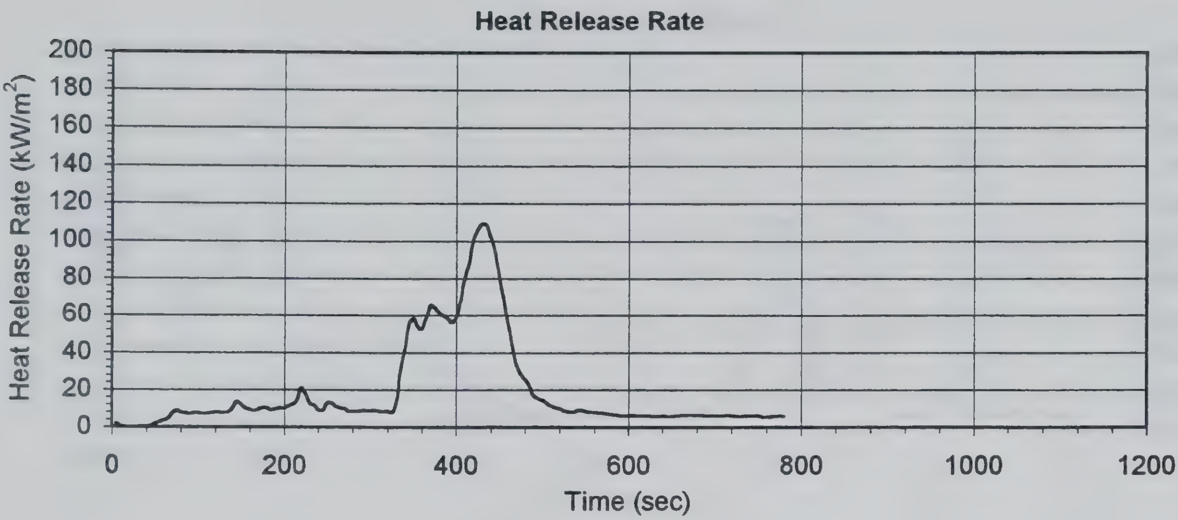
35 kW/m^2, Test #3

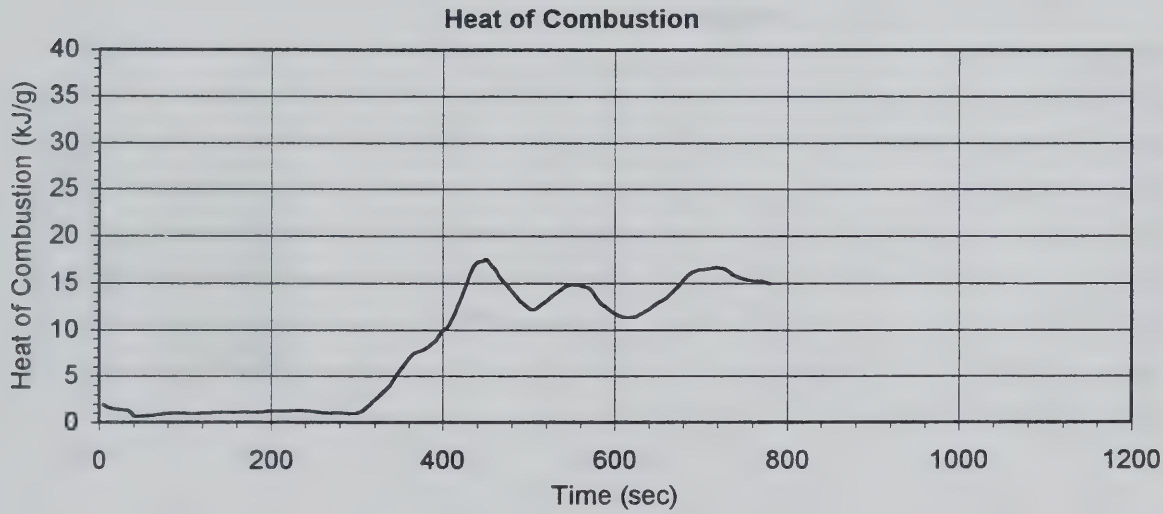


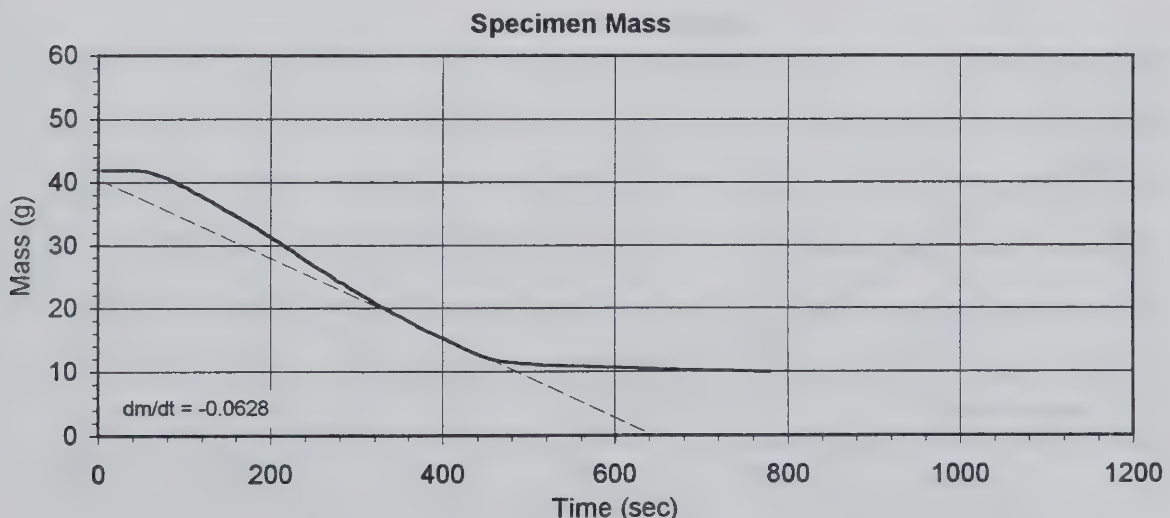




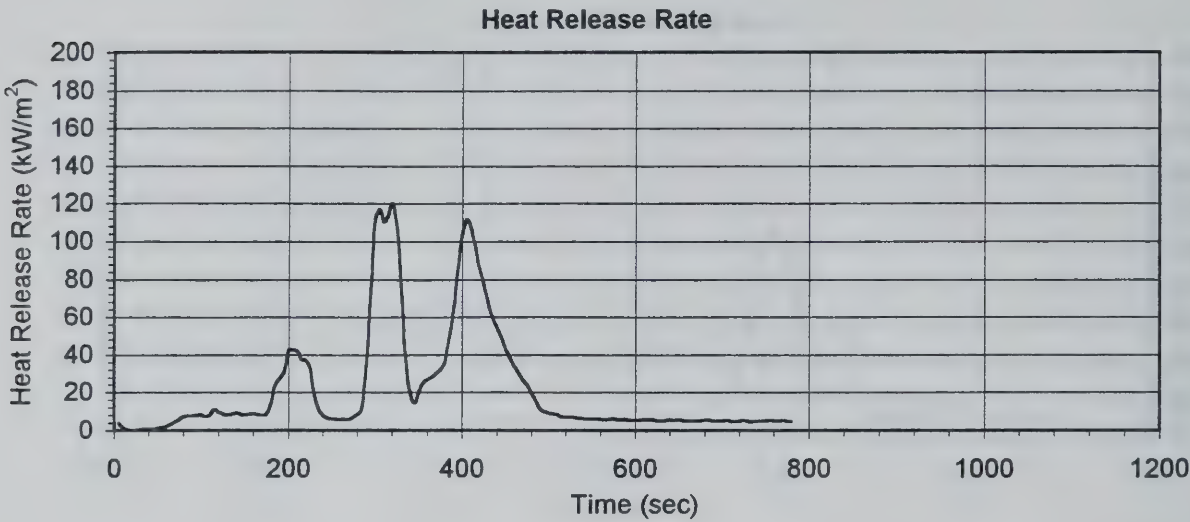
Cone Calorimeter Data R 4.07 F.R. PVC
35 kW/m^2, Test #4

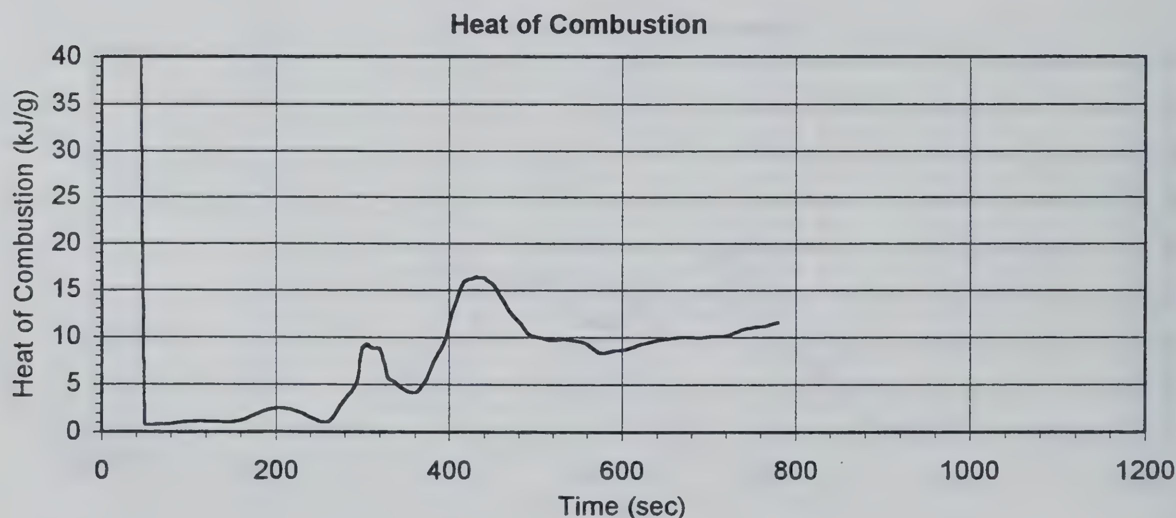


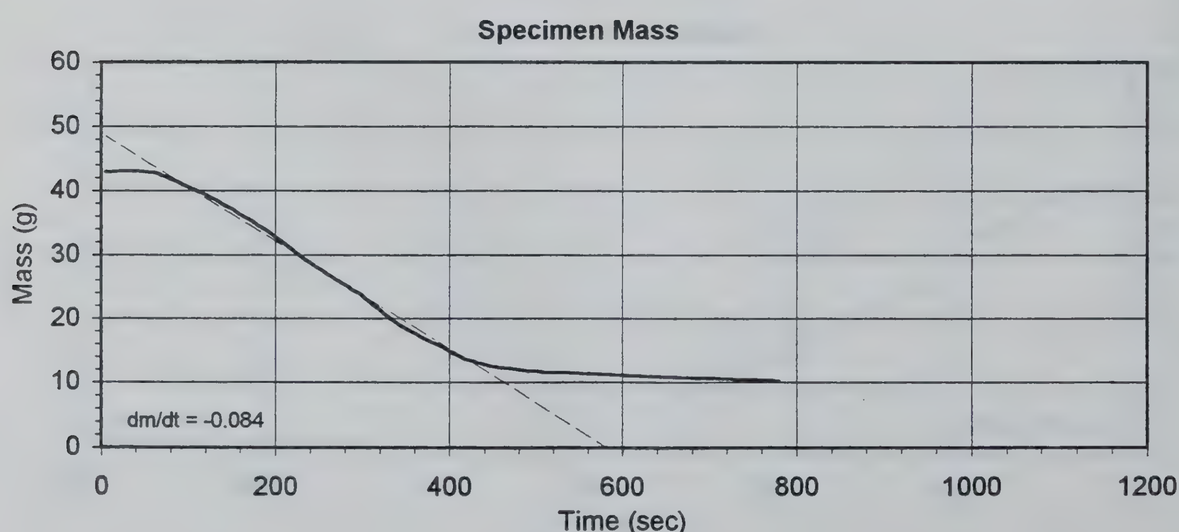




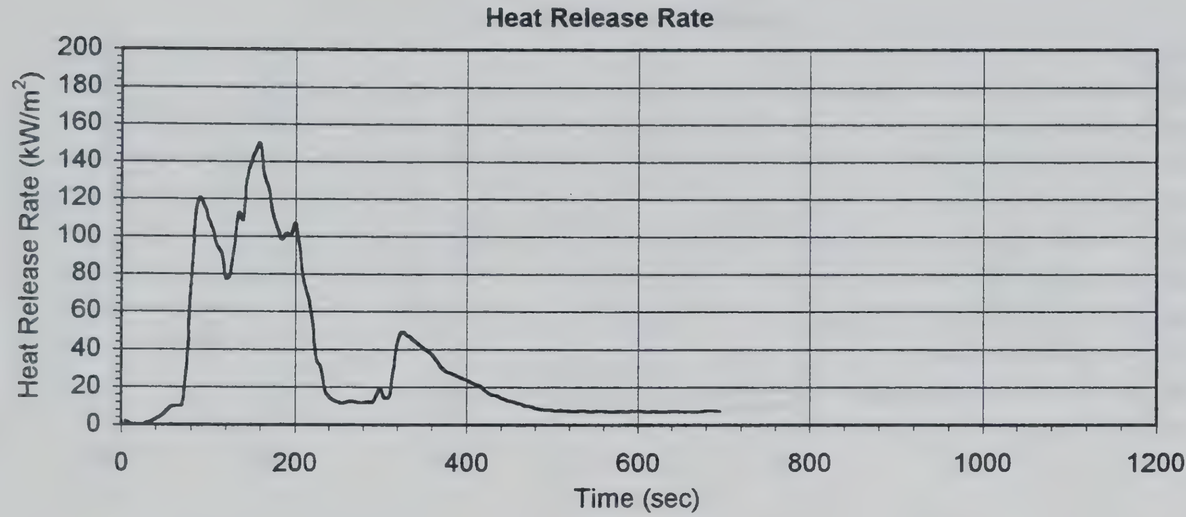
Cone Calorimeter Data R 4.07 F.R. PVC
35 kW/m^2, Test #5

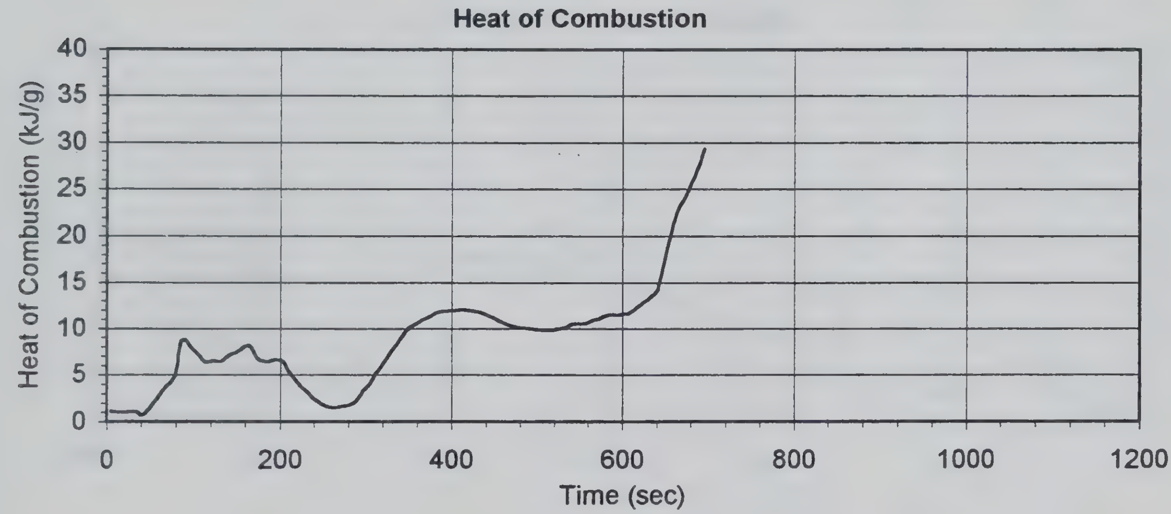


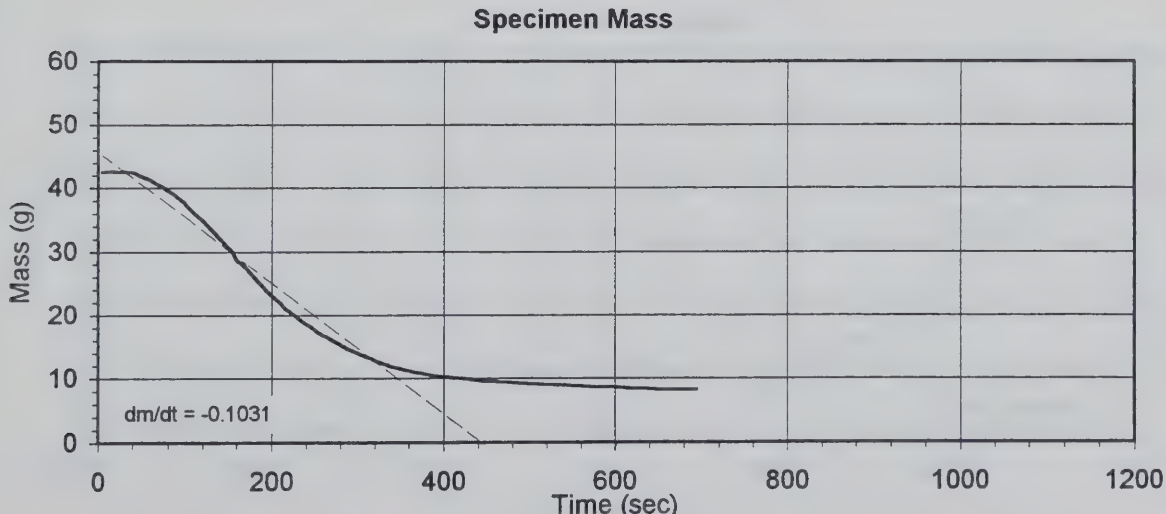




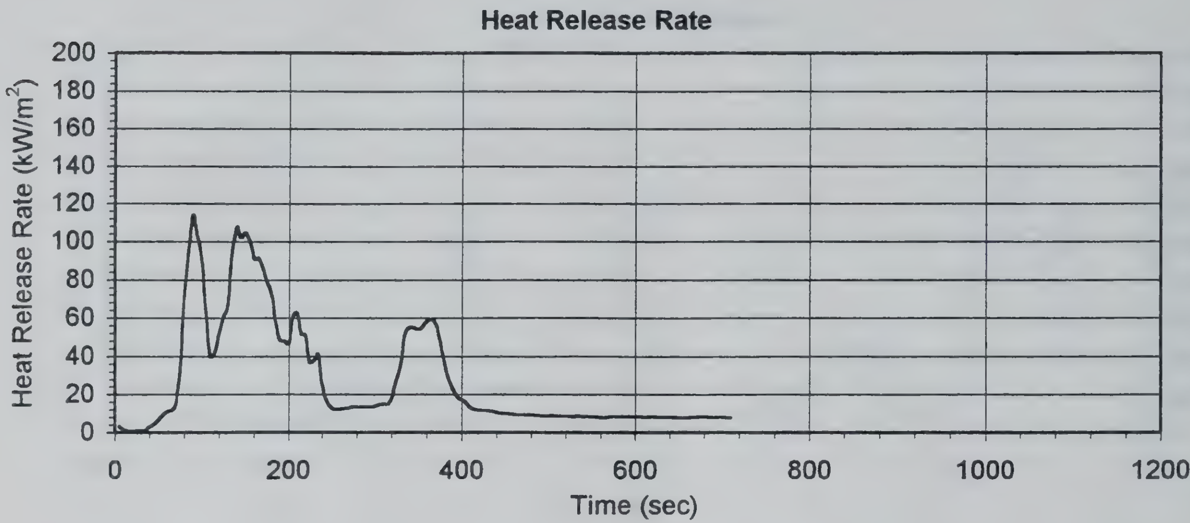
Cone Calorimeter Data R 4.07 F.R. PVC
40 kW/m², Test #1

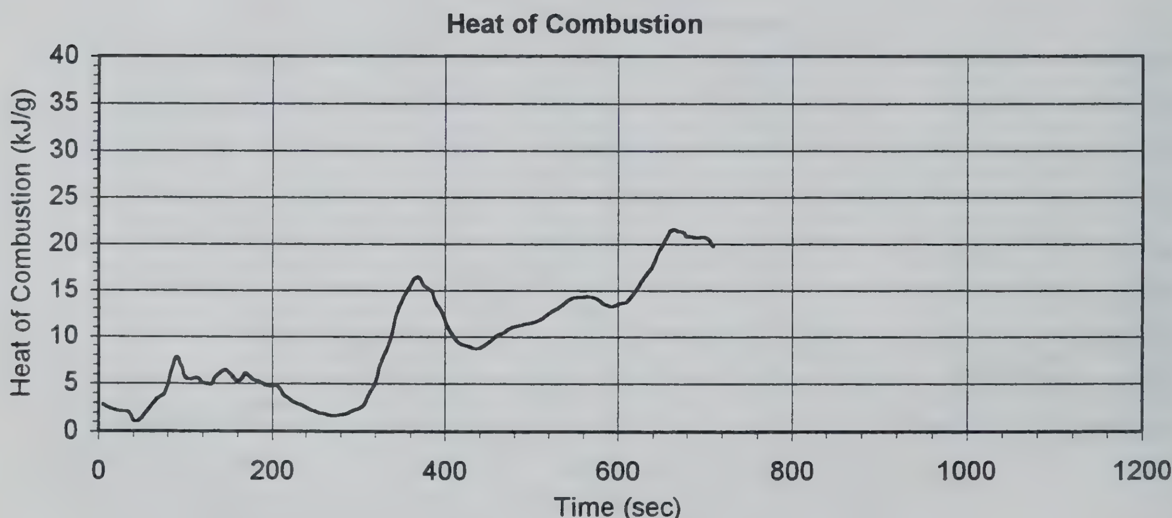


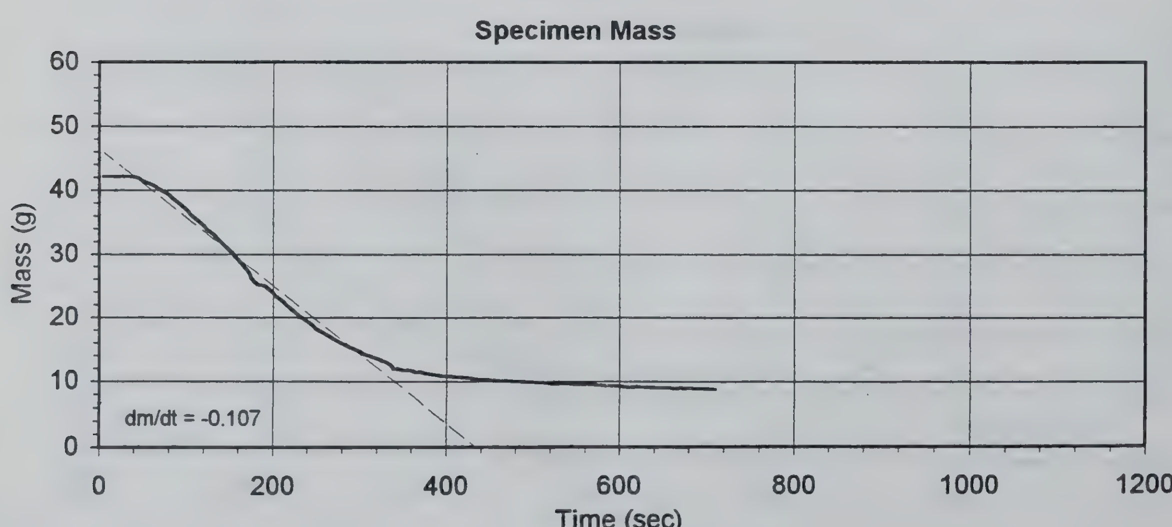




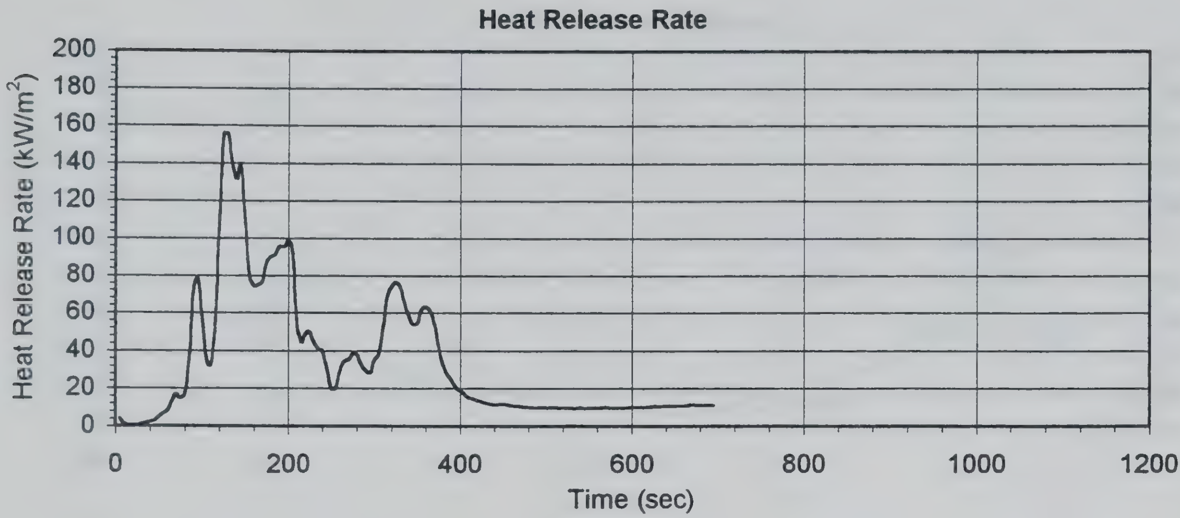
Cone Calorimeter Data R 4.07 F.R. PVC
40 kW/m^2, Test #2

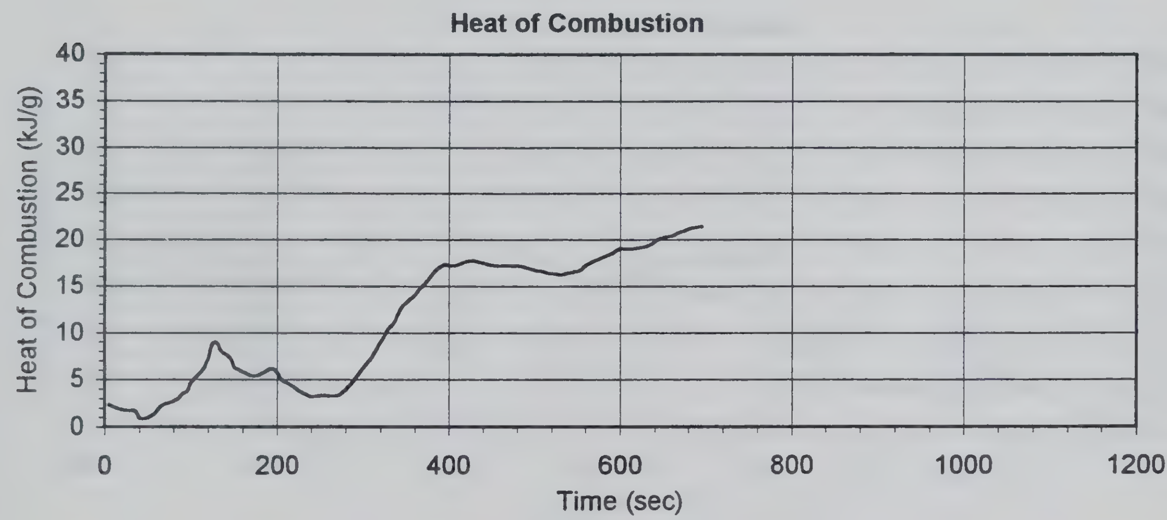


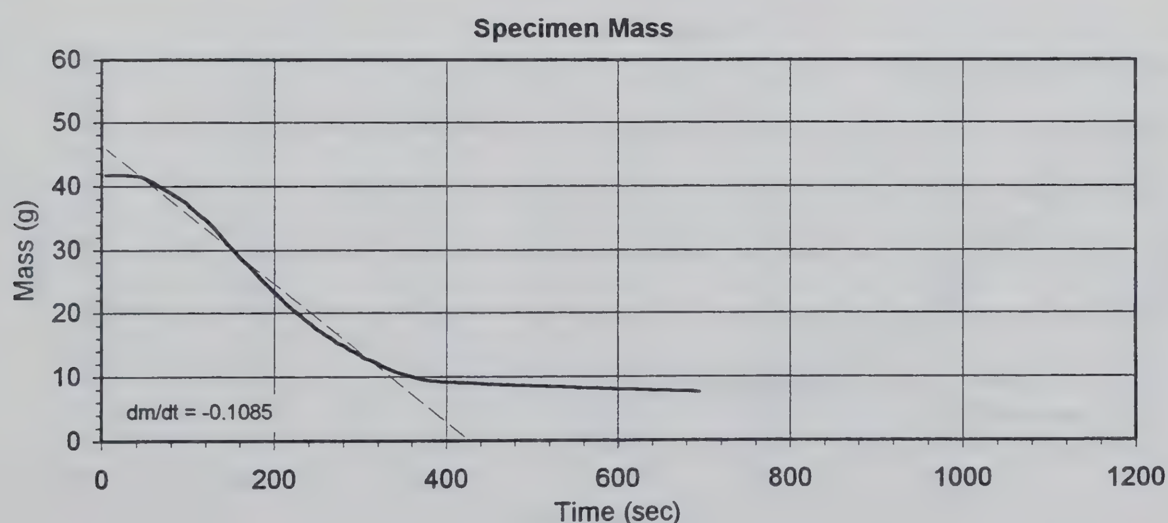




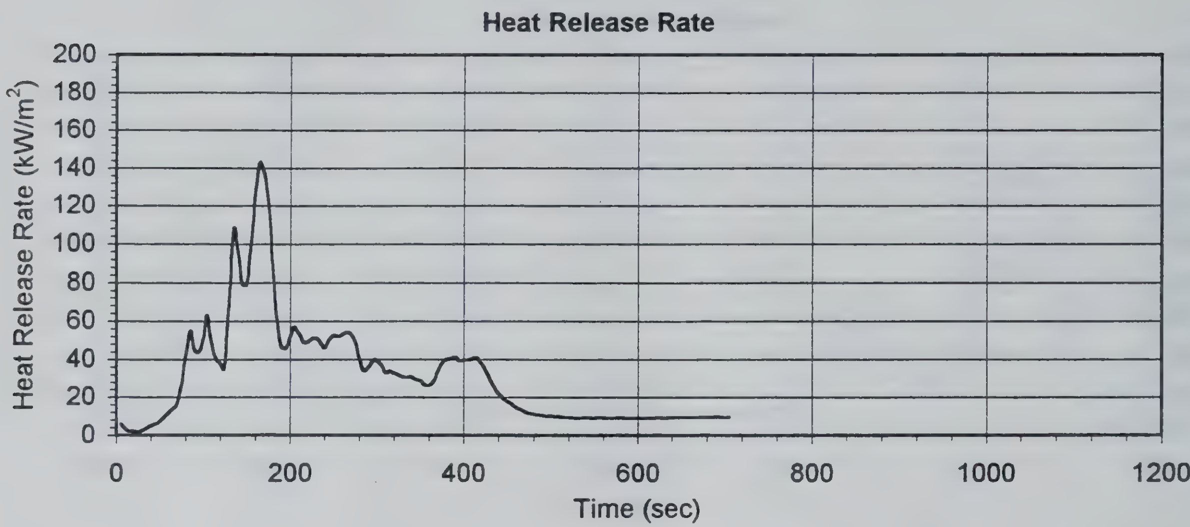
Cone Calorimeter Data R 4.07 F.R. PVC
40 kW/m^2, Test #3

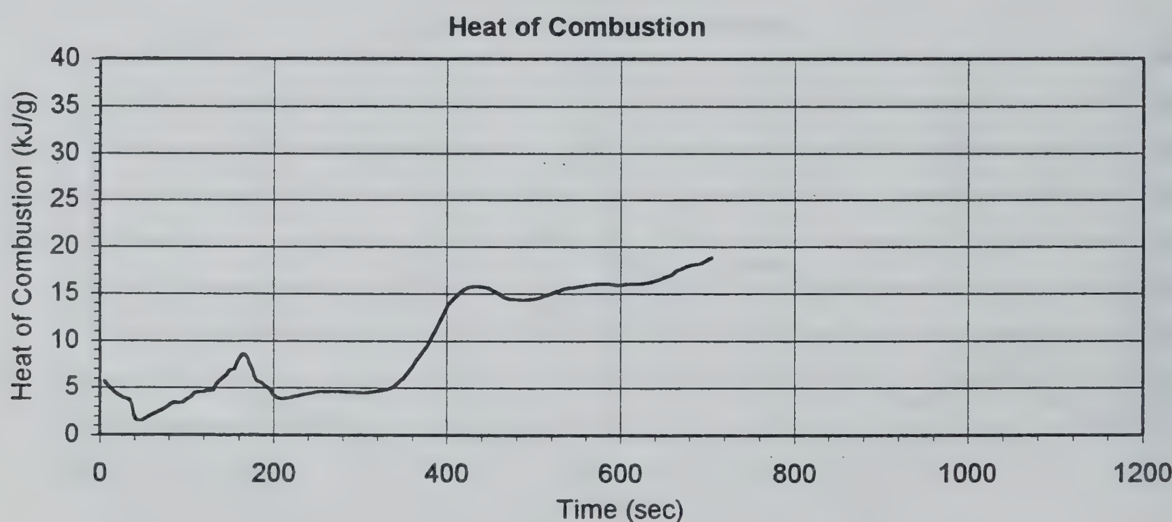


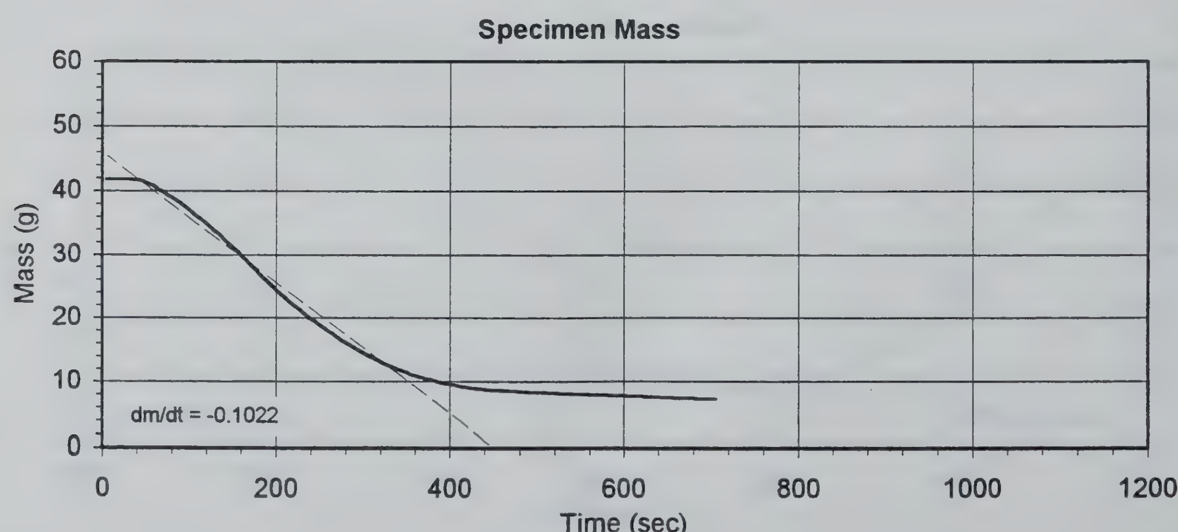




Cone Calorimeter Data R 4.07 F.R. PVC
40 kW/m^2, Test #4

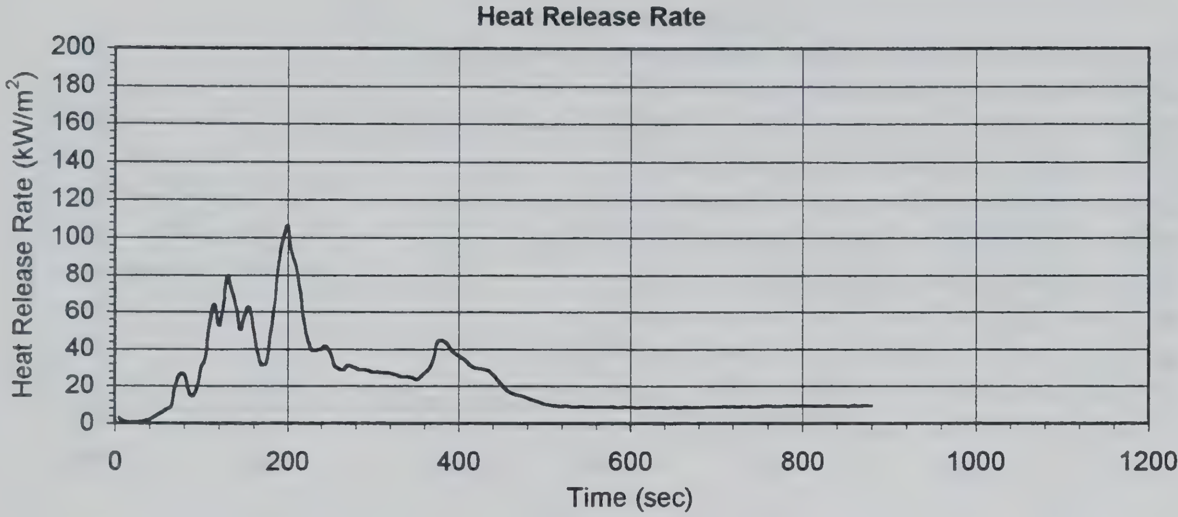


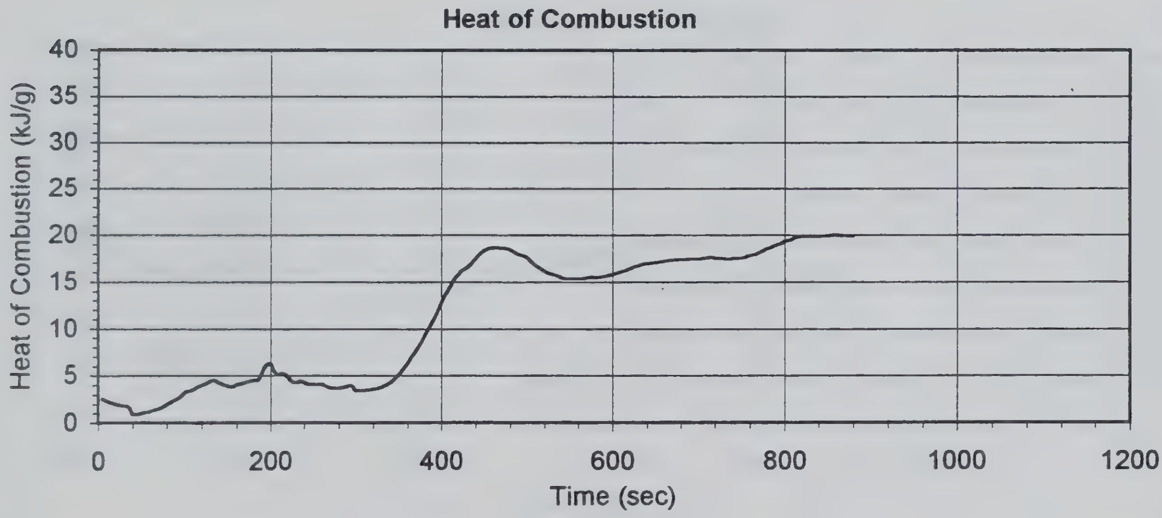


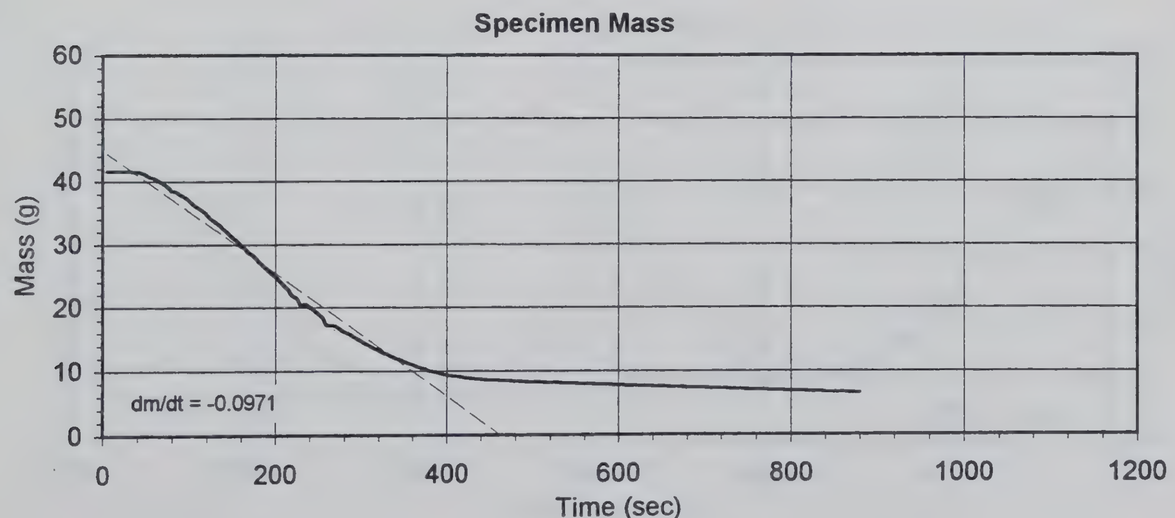


Cone Calorimeter Data R 4.07 F.R. PVC

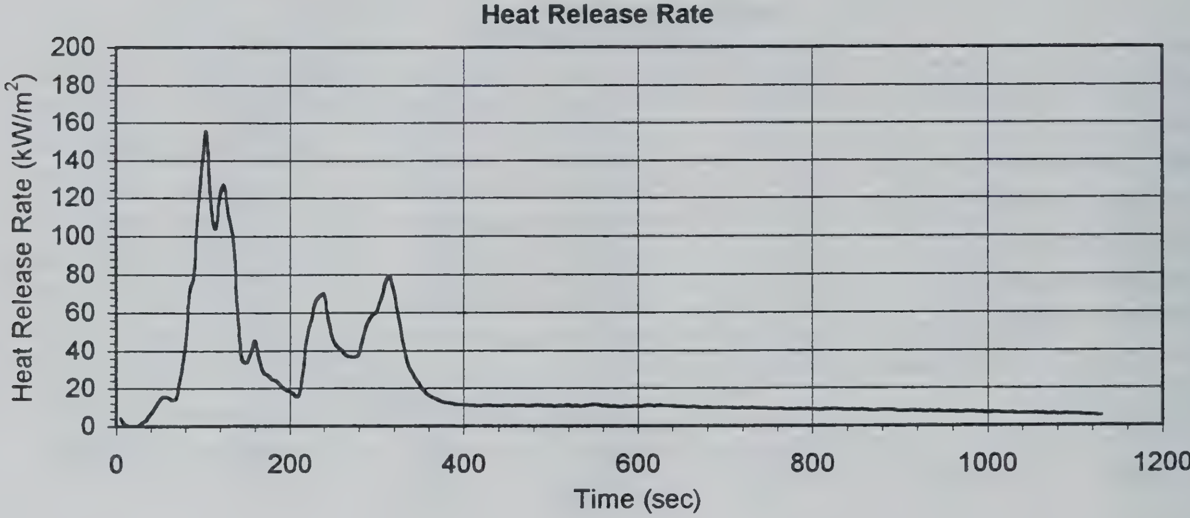
40 kW/m^2, Test #5

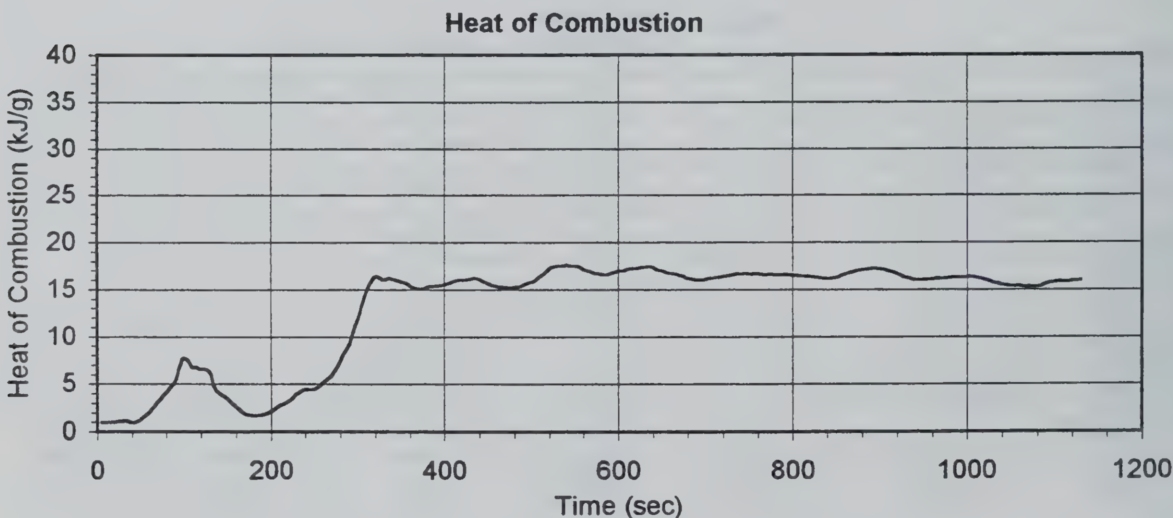


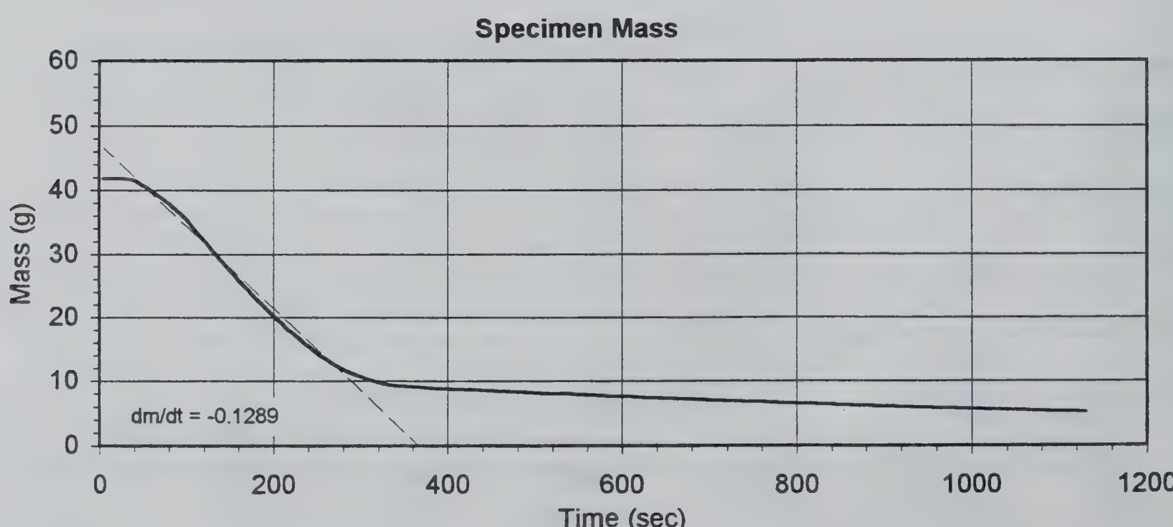




Cone Calorimeter Data R 4.07 F.R. PVC
50 kW/m^2, Test #1

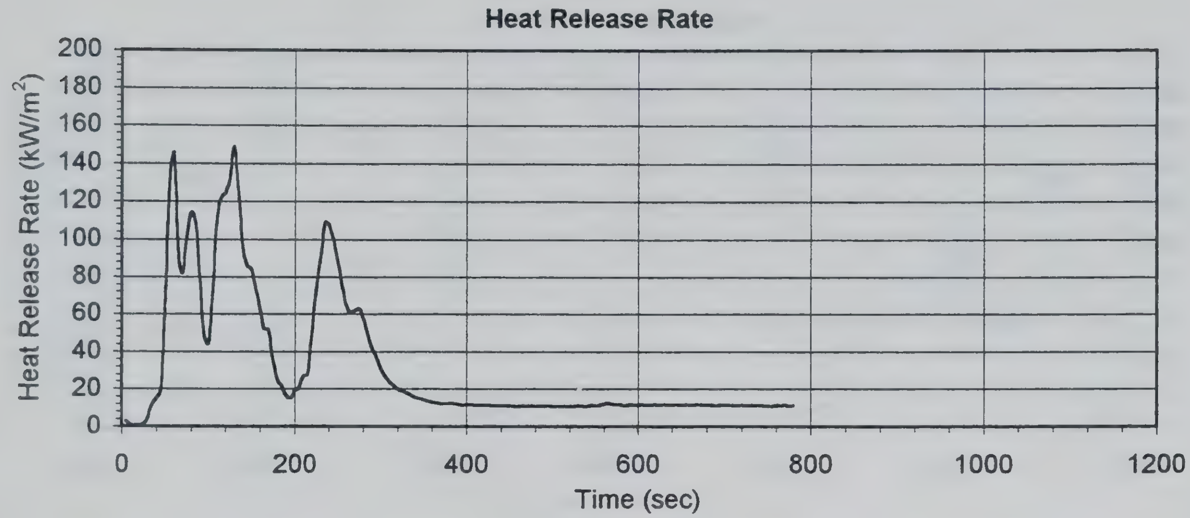


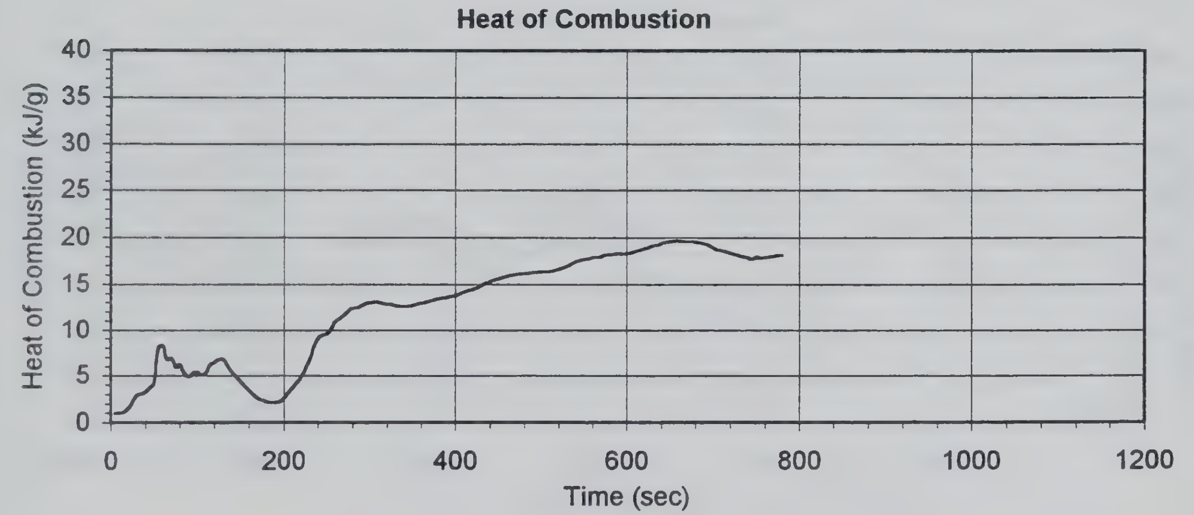


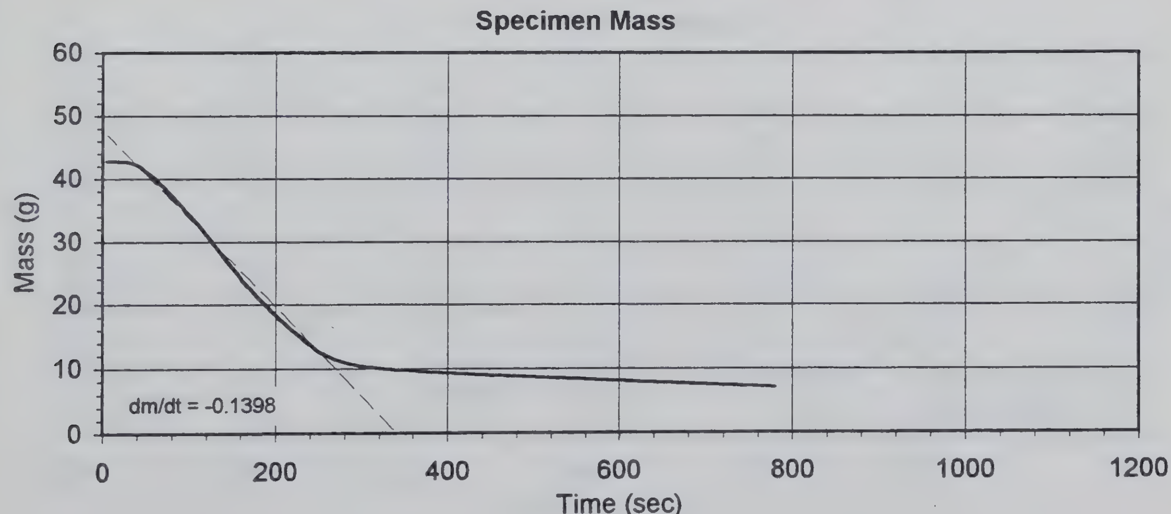


Cone Calorimeter Data R 4.07 F.R. PVC

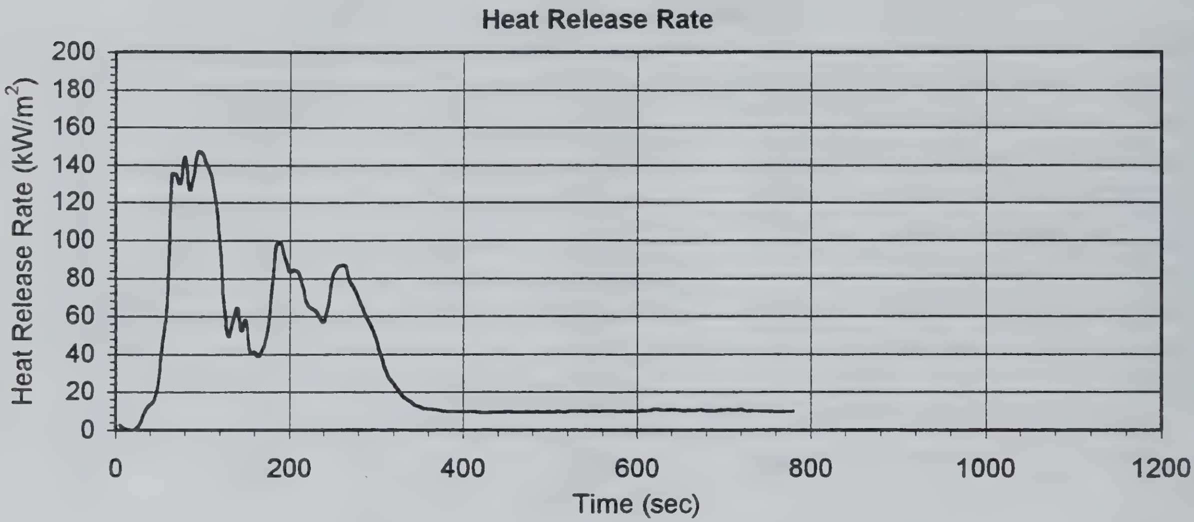
50 kW/m^2, Test #2

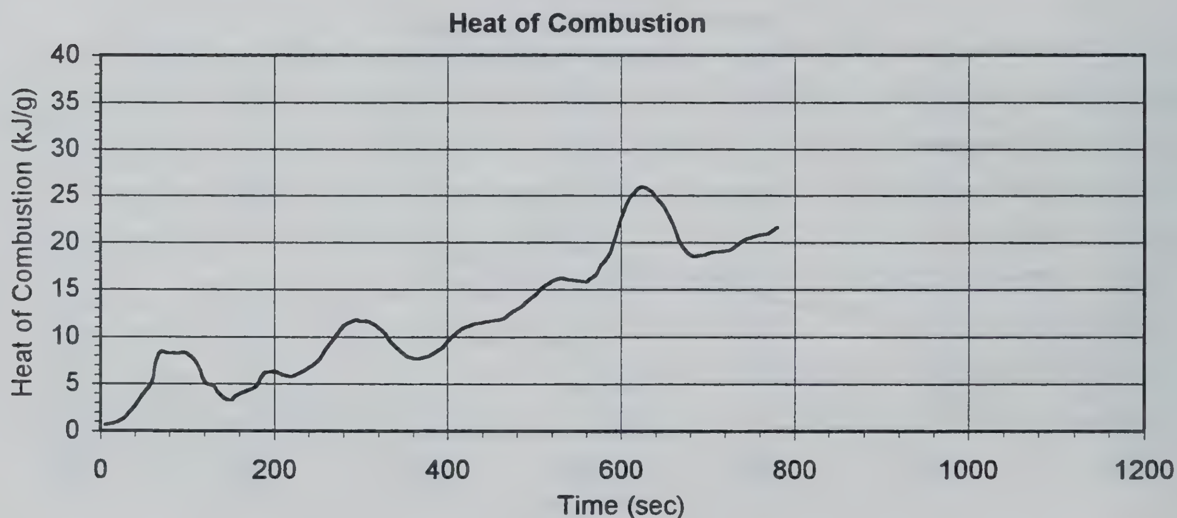


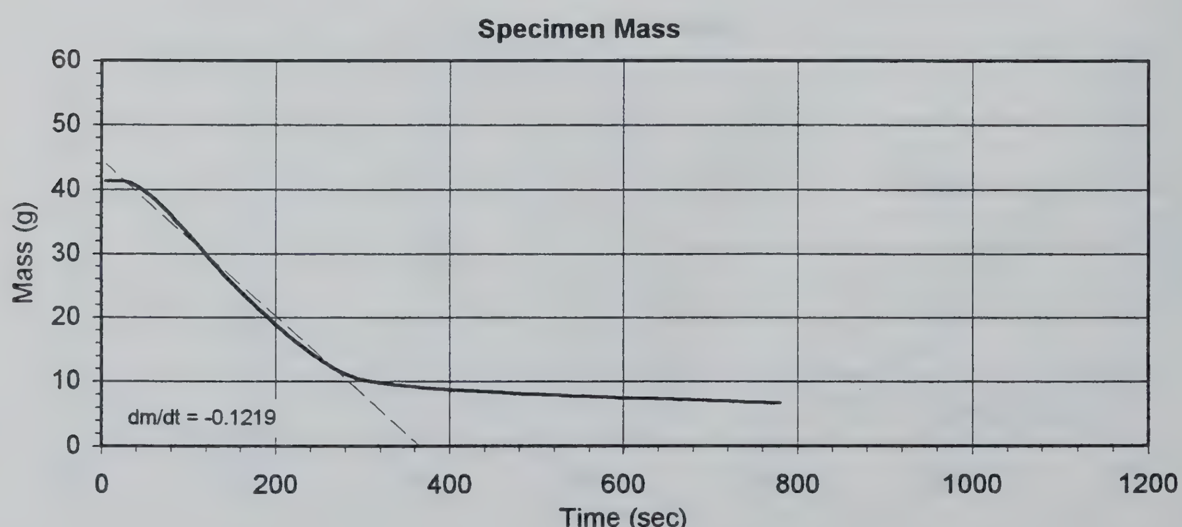




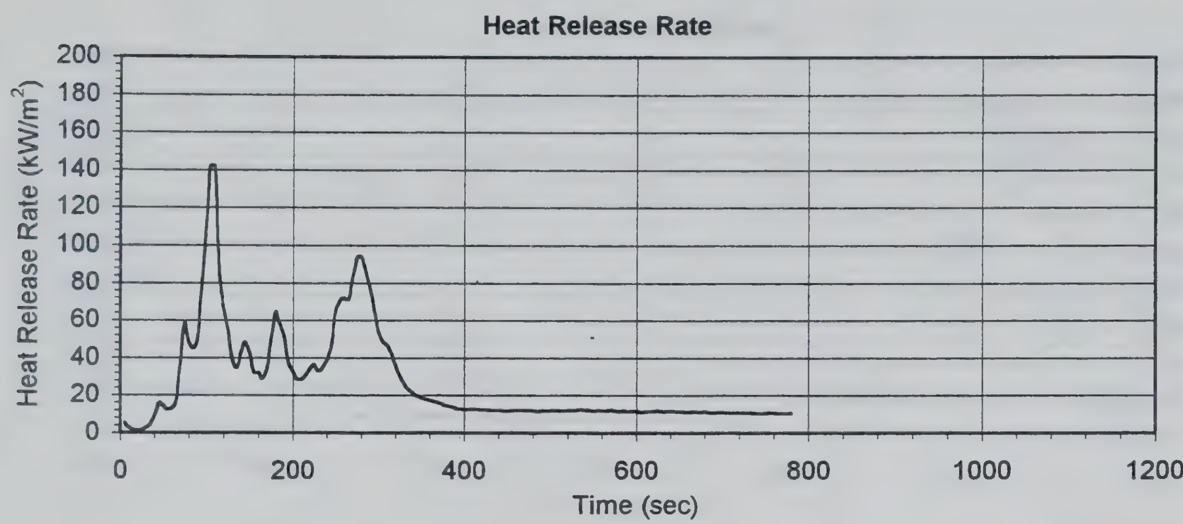
Cone Calorimeter Data R 4.07 F.R. PVC
50 kW/m^2, Test #3

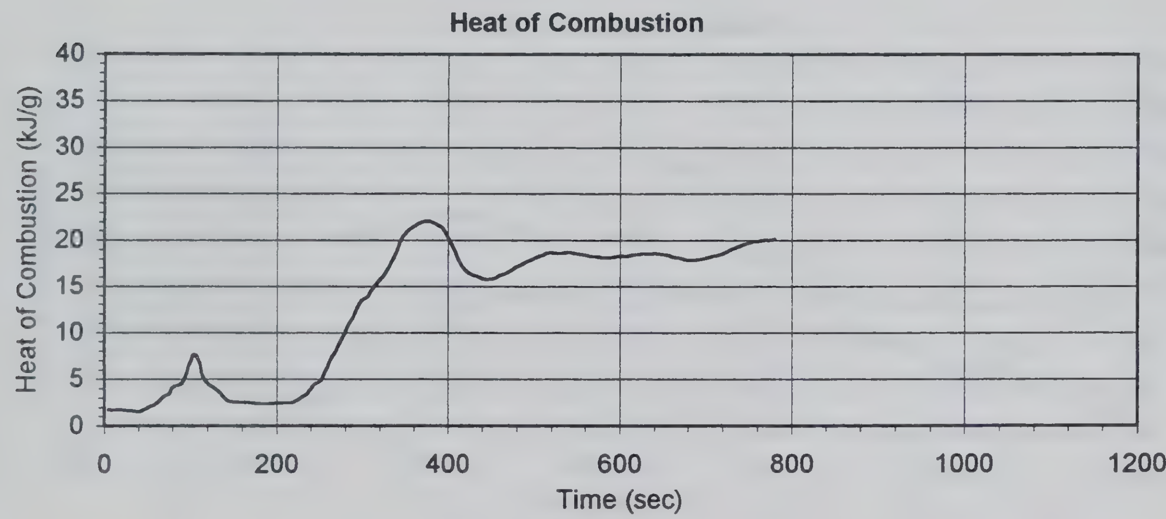


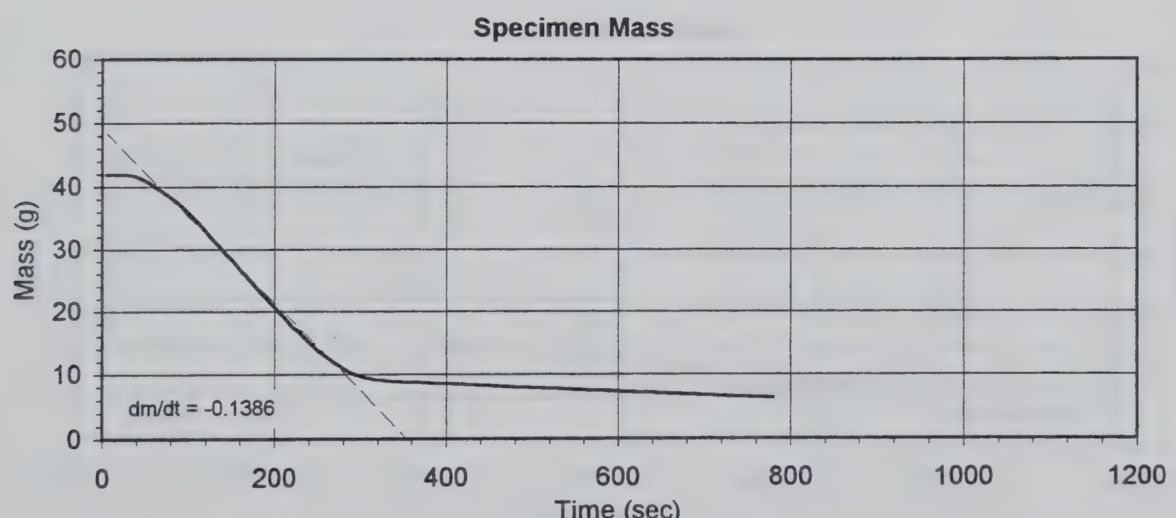




Cone Calorimeter Data R 4.07 F.R. PVC
50 kW/m², Test #4

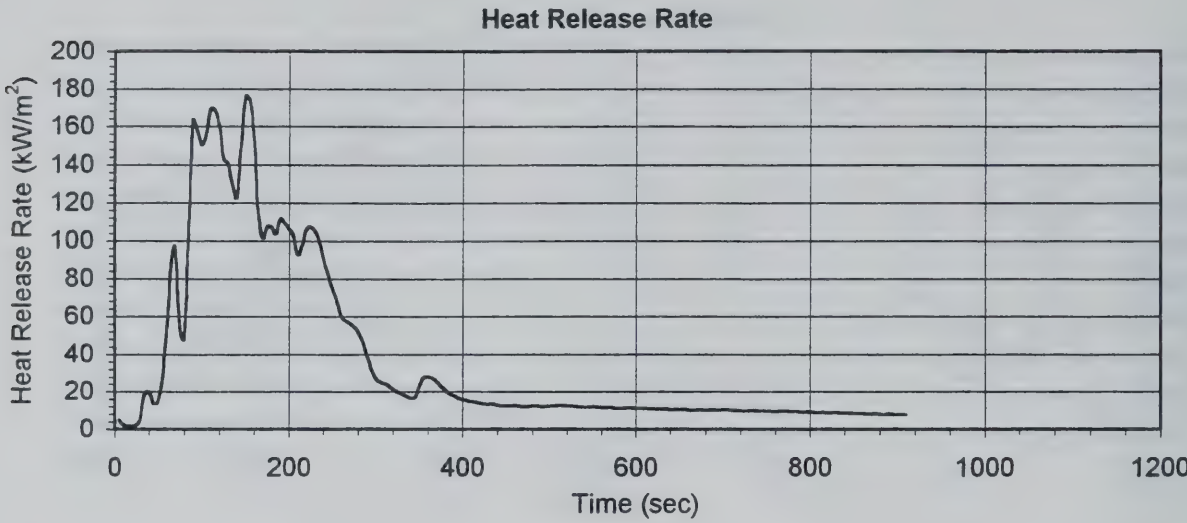


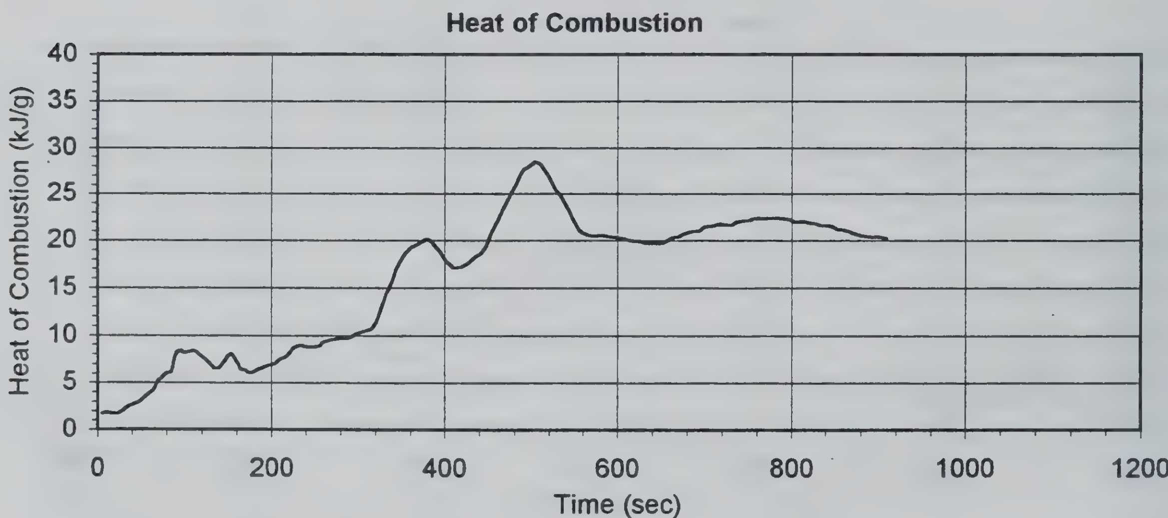


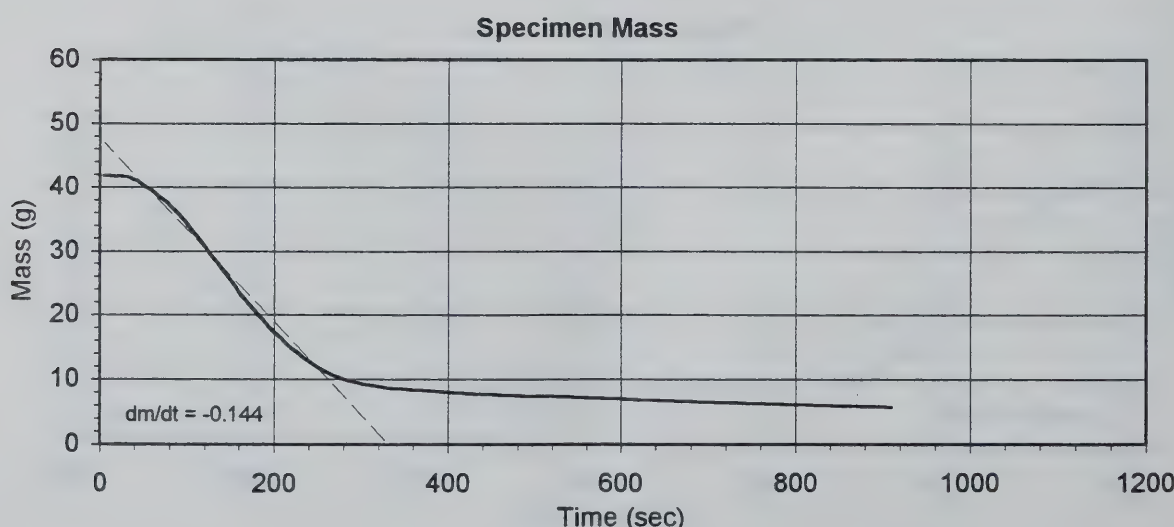


Cone Calorimeter Data R 4.07 F.R. PVC

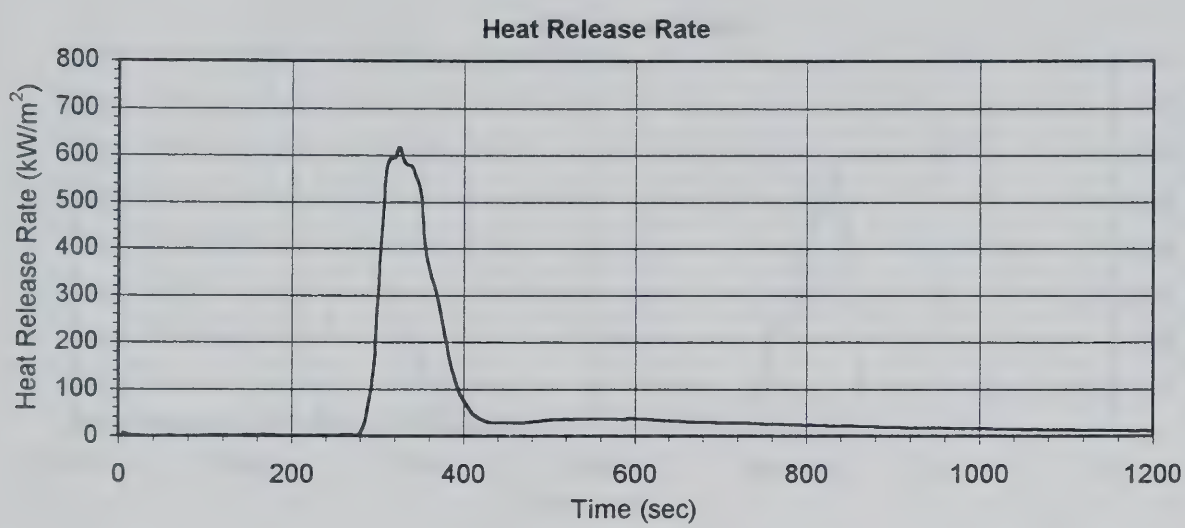
50 kW/m², Test #5

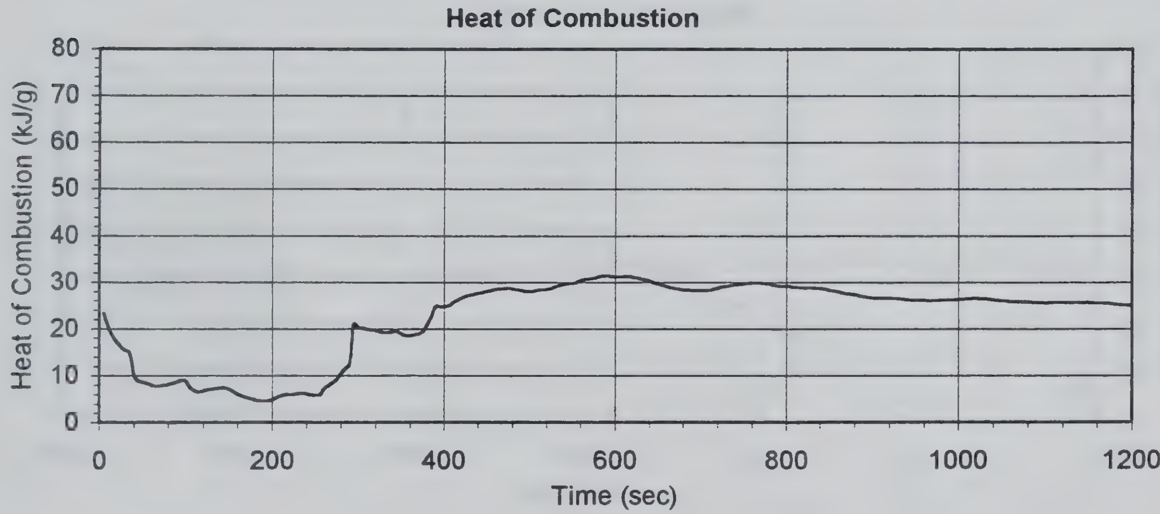


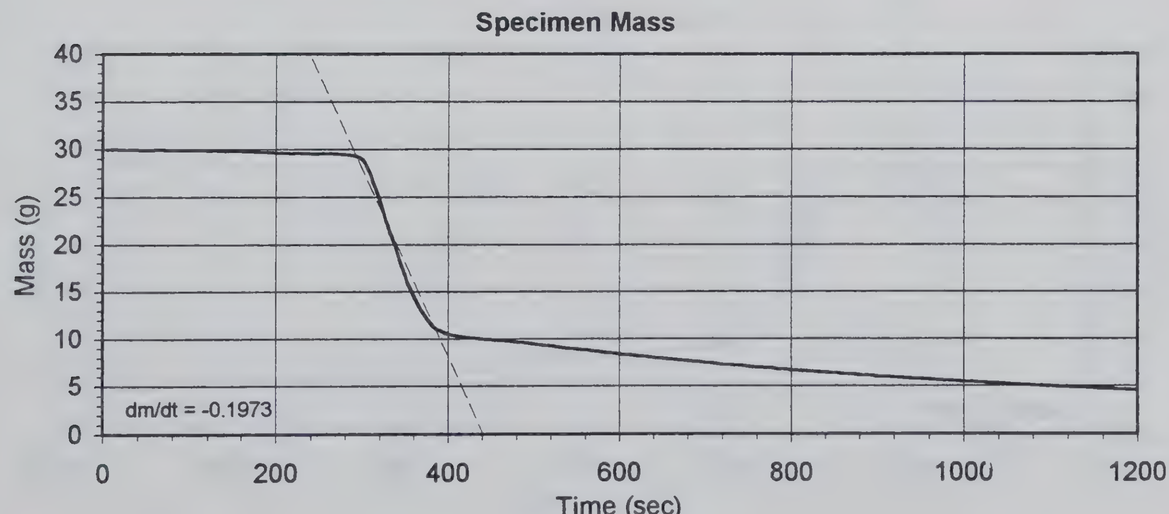




Cone Calorimeter Data R 4.08 3-Layered Polycarbonate Panel
35 kW/m², Test #1







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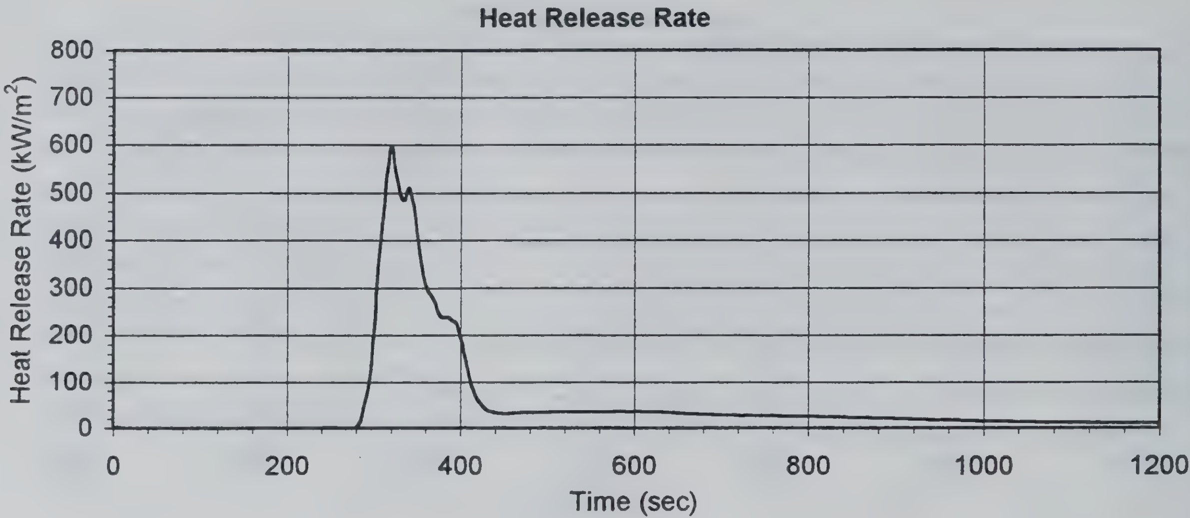
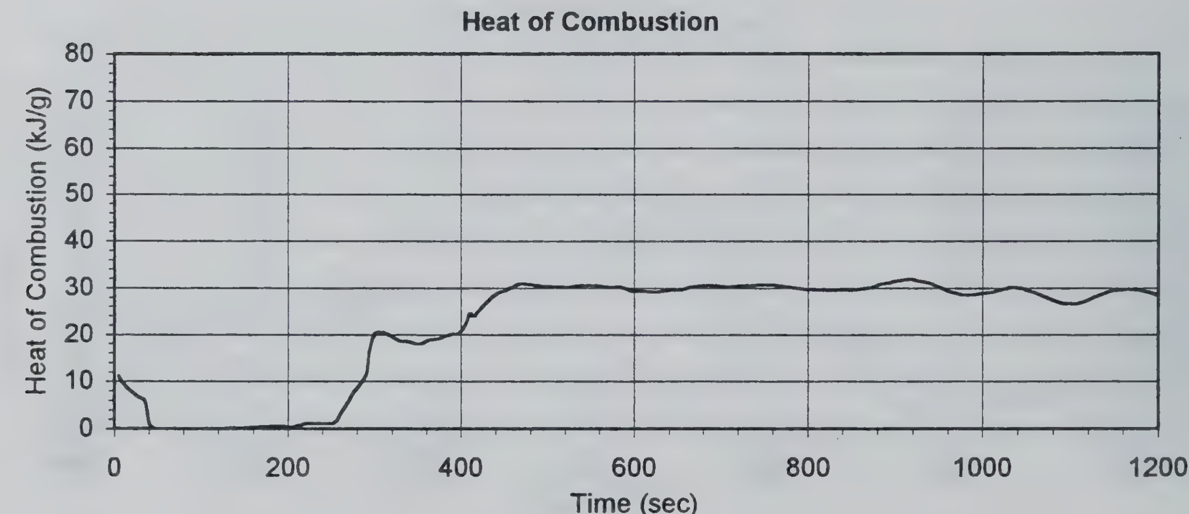
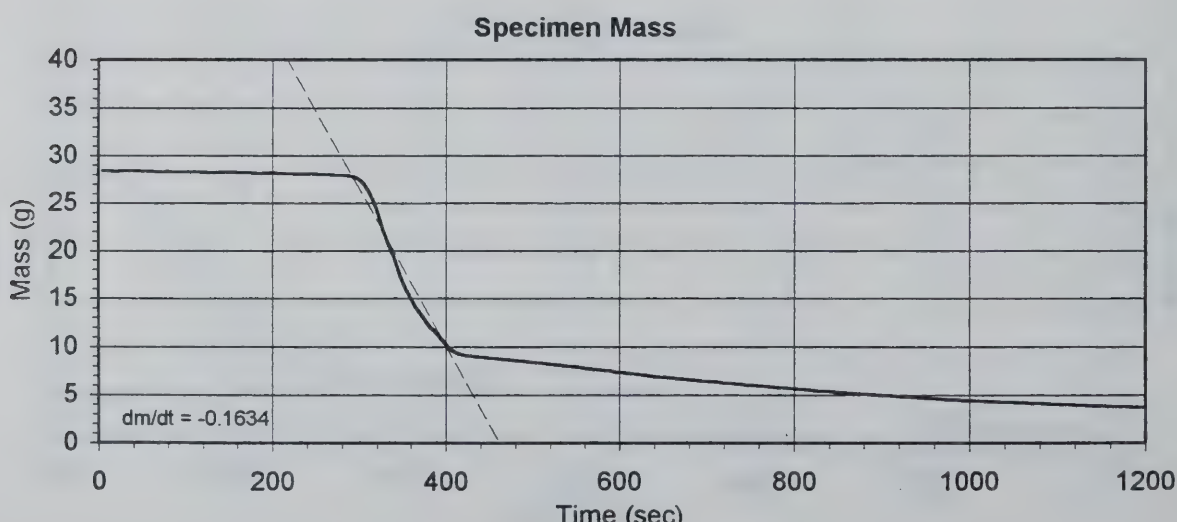
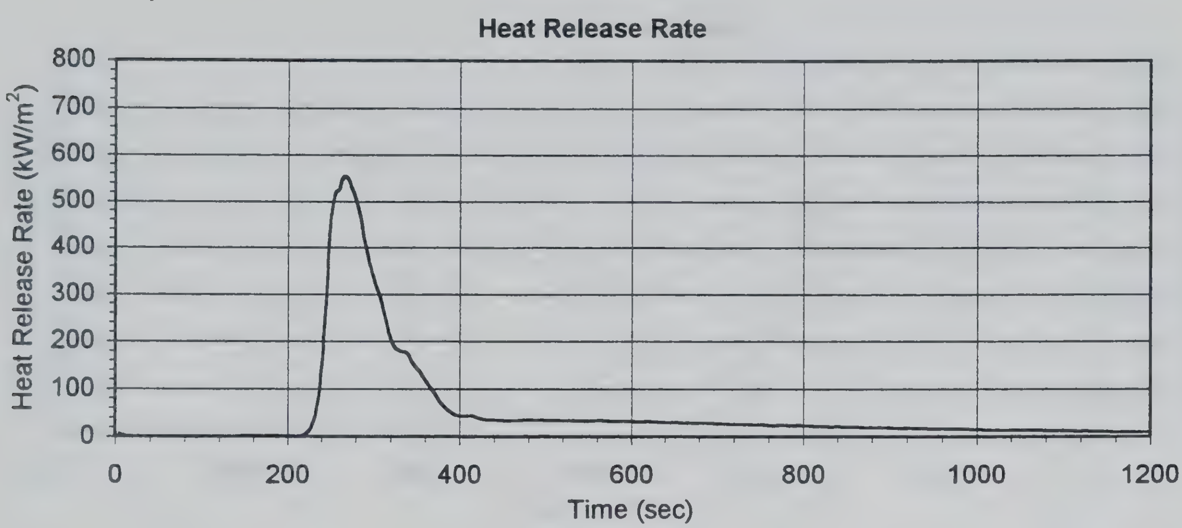
35 kW/m², Test #2

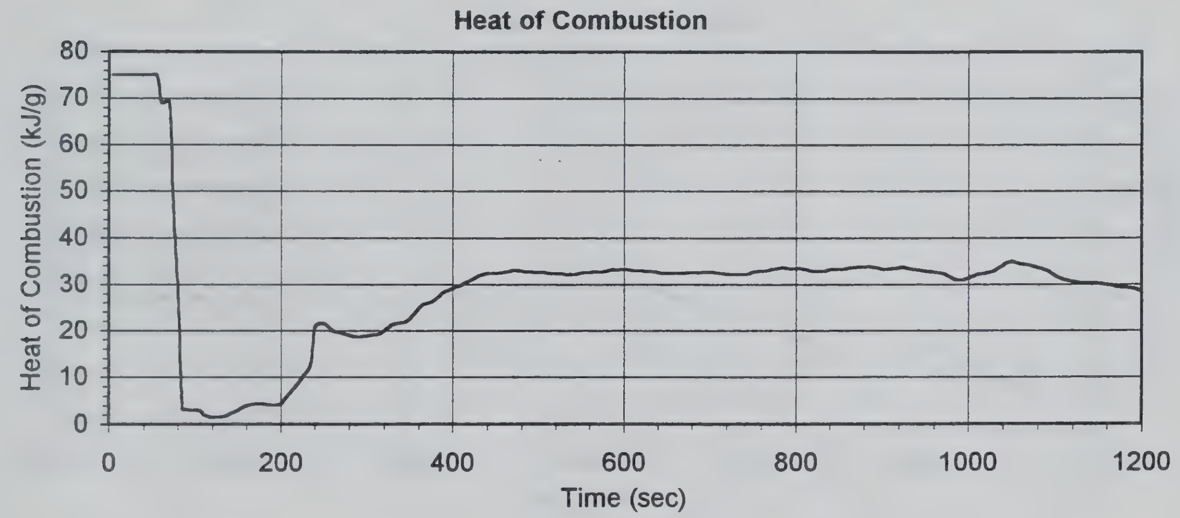


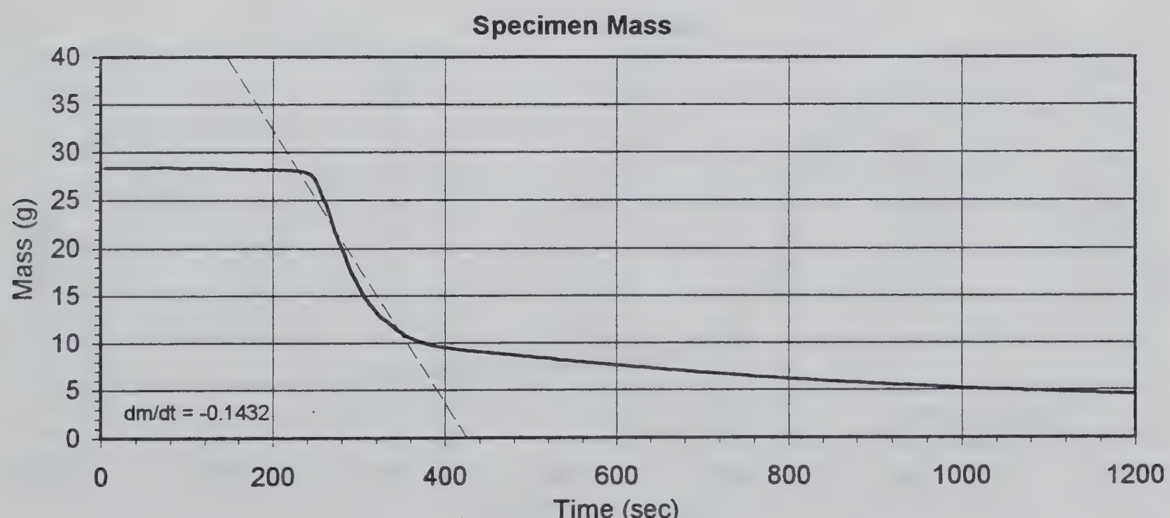




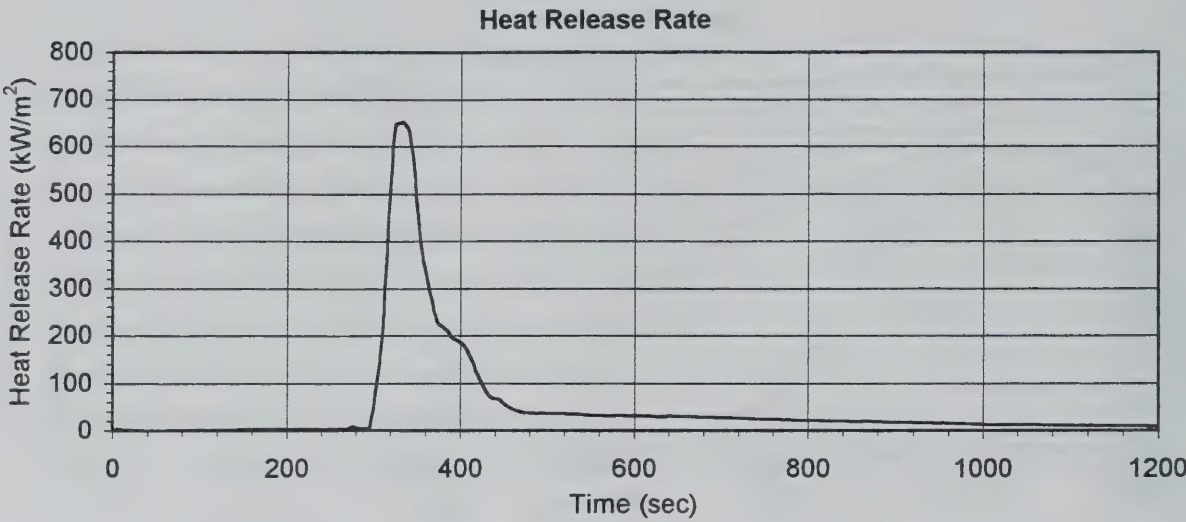
Cone Calorimeter Data R 4.08 3-Layered Polycarbonate Panel
35 kW/m^2, Test #3

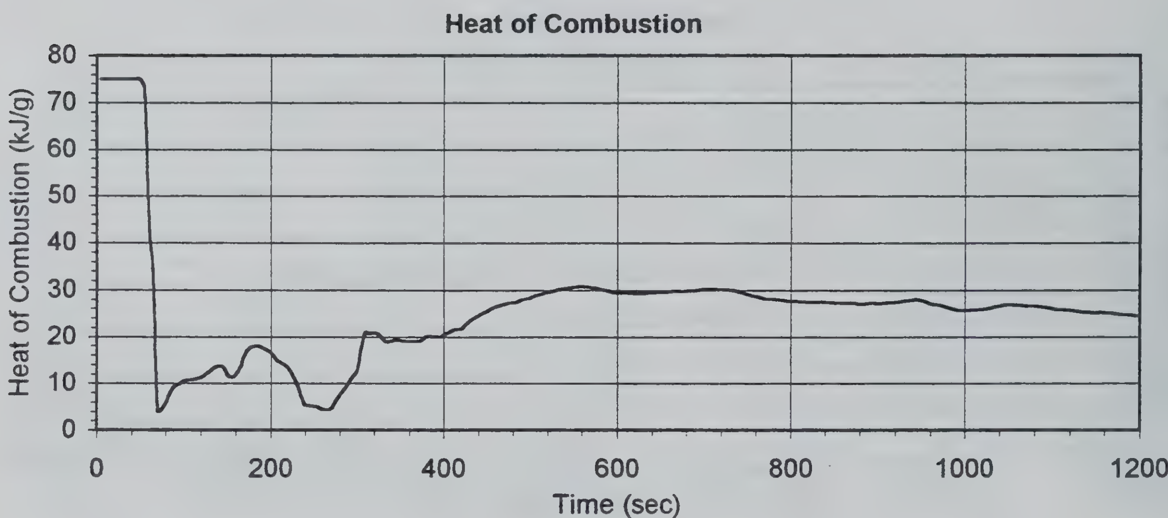


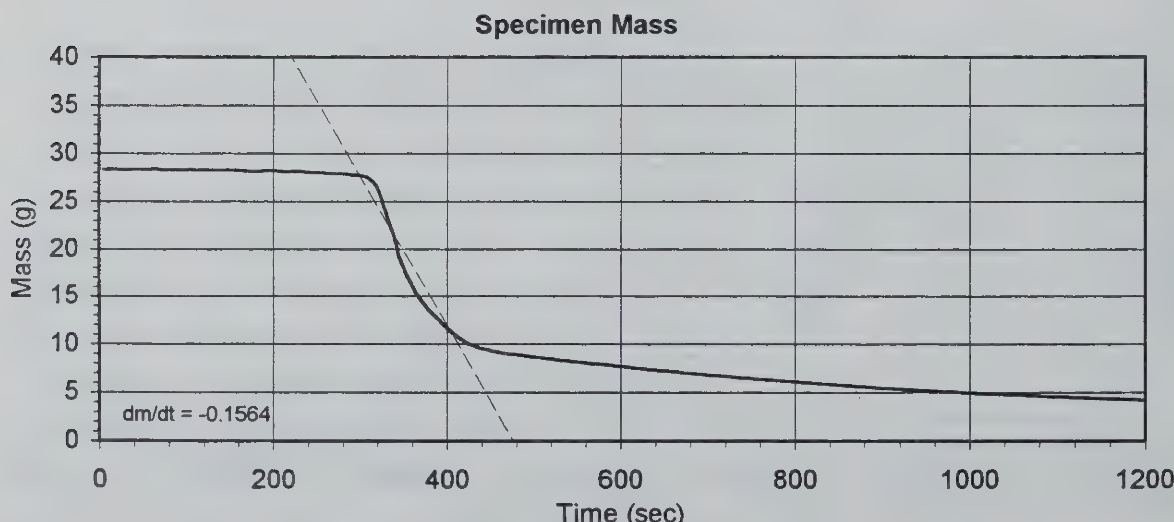




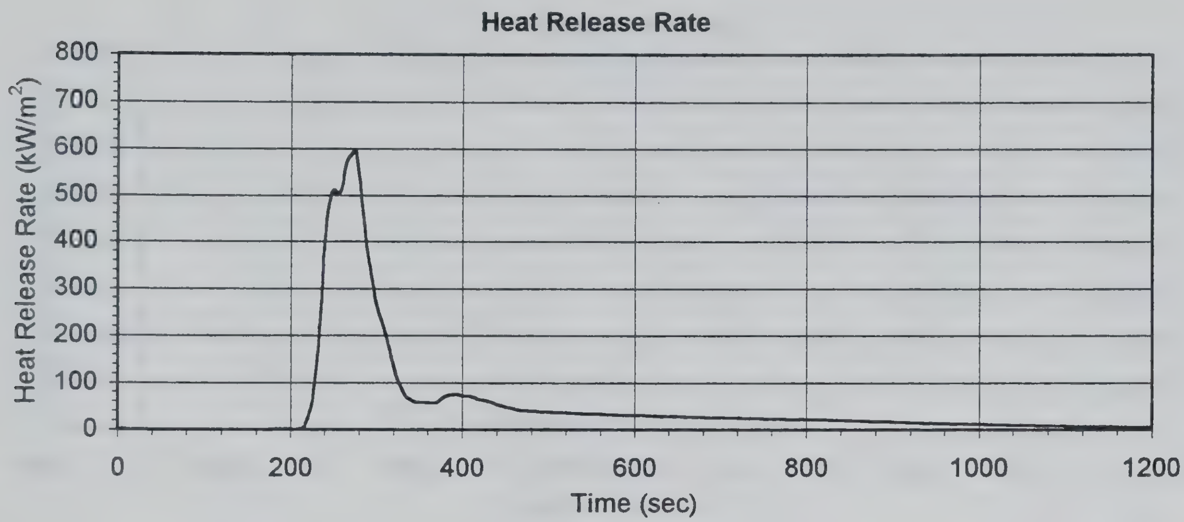
Cone Calorimeter Data R 4.08 3-Layered Polycarbonate Panel
35 kW/m², Test #4

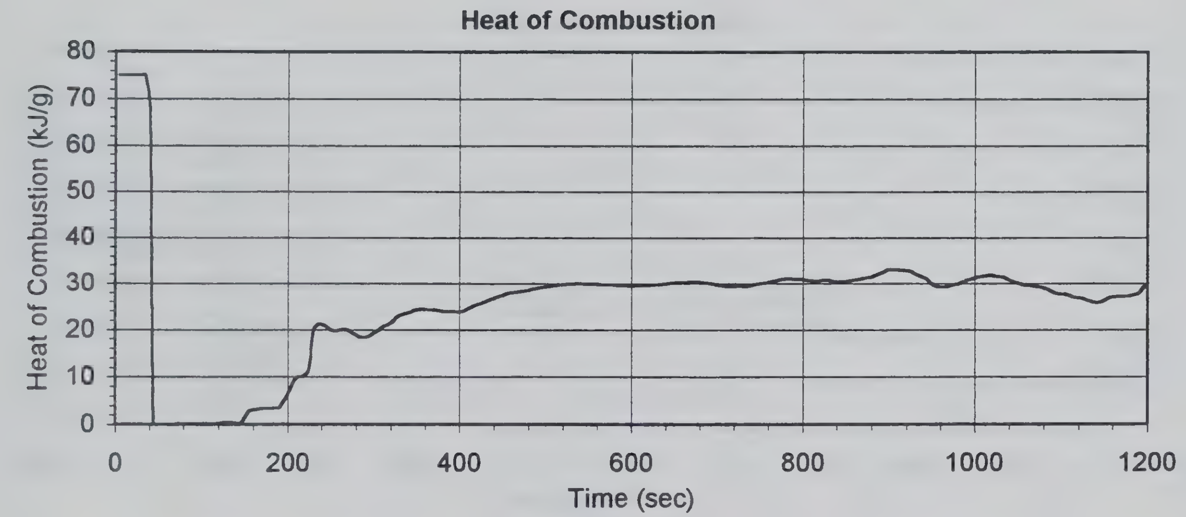


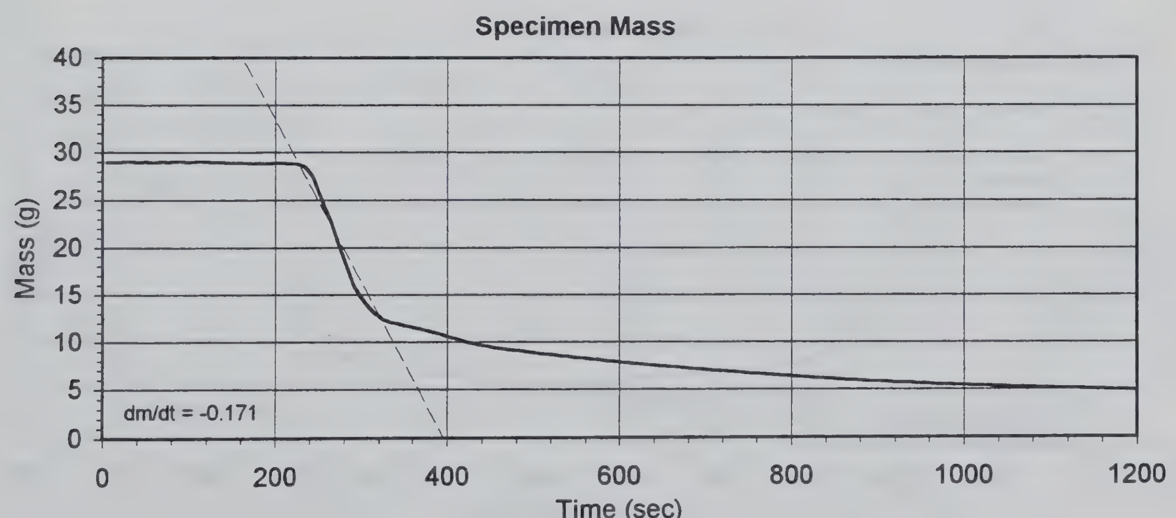




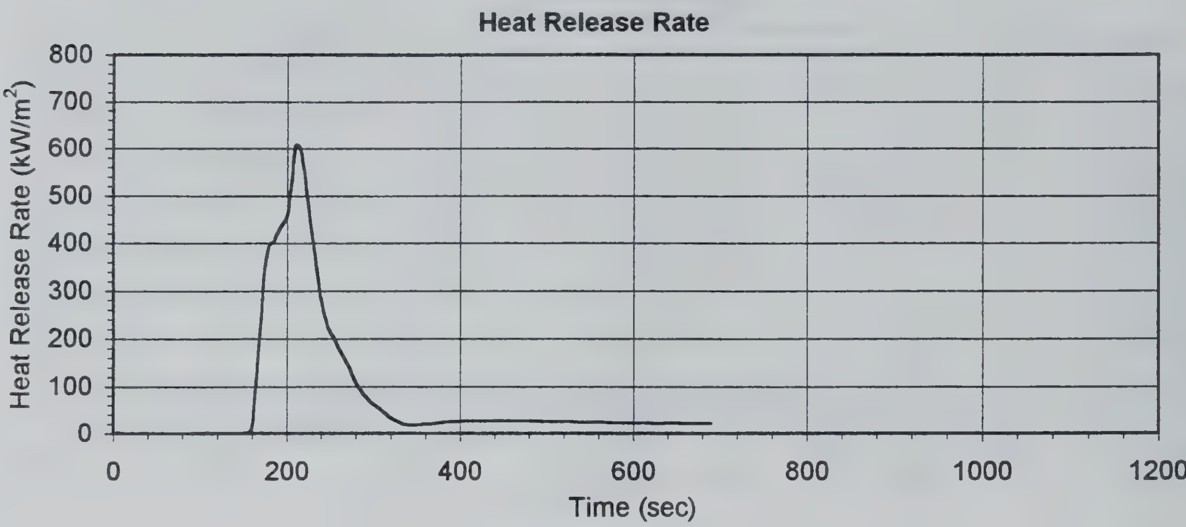
Cone Calorimeter Data R 4.08 3-Layered Polycarbonate Panel
35 kW/m^2, Test #5

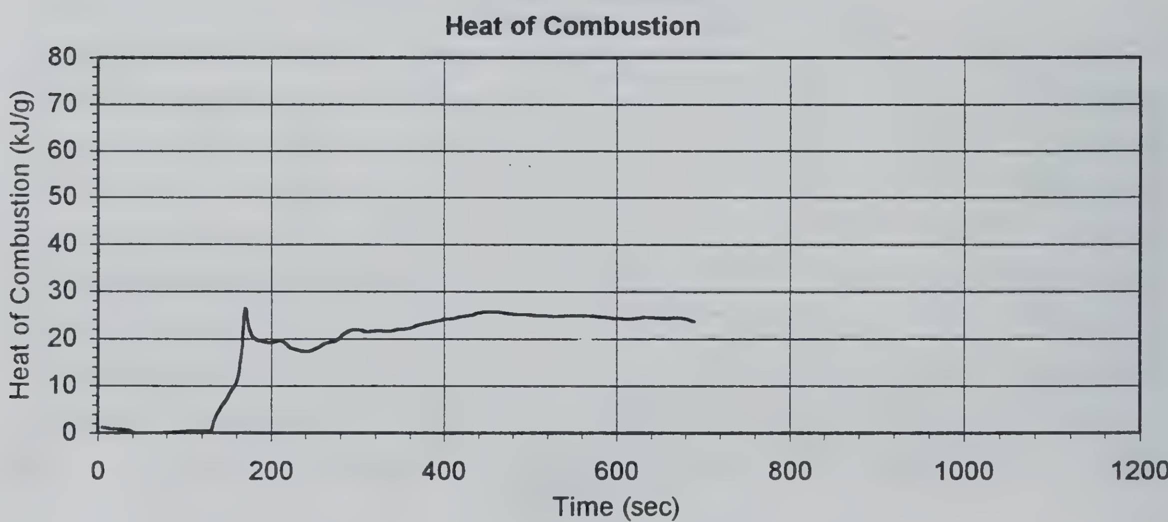


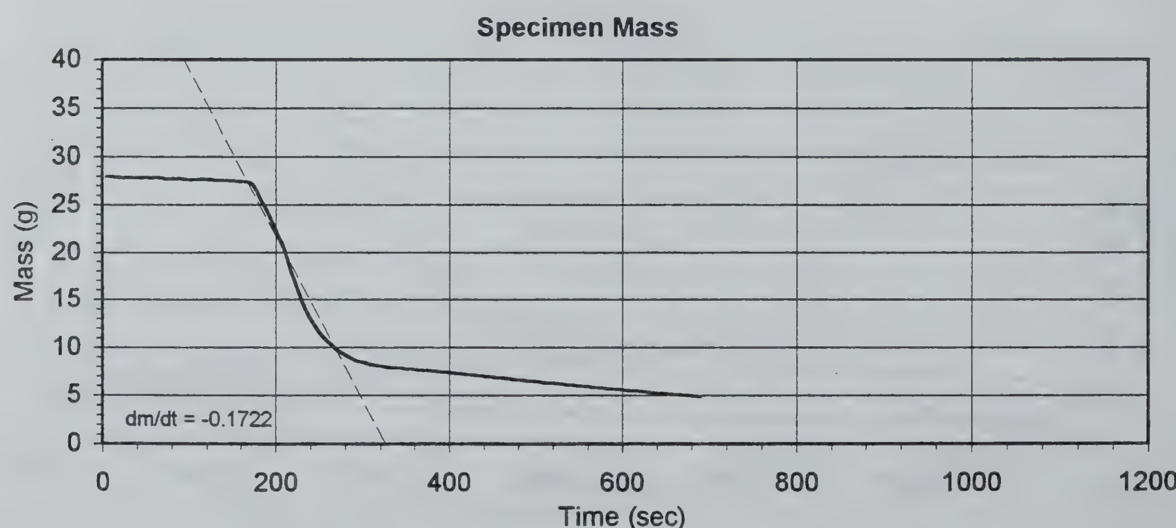




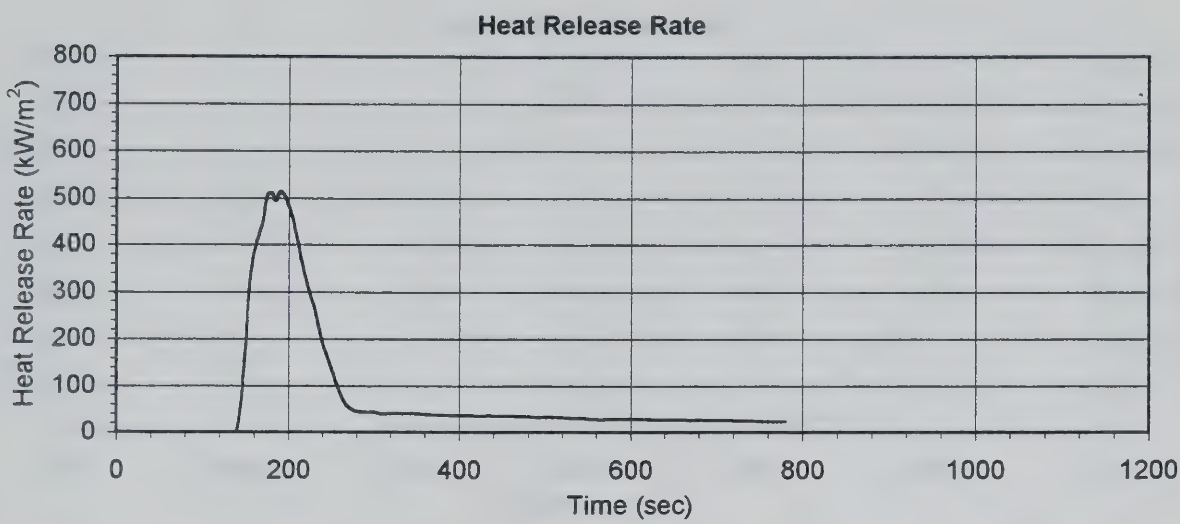
Cone Calorimeter Data R 4.08 3-Layered Polycarbonate Panel
40 kW/m^2, Test #1

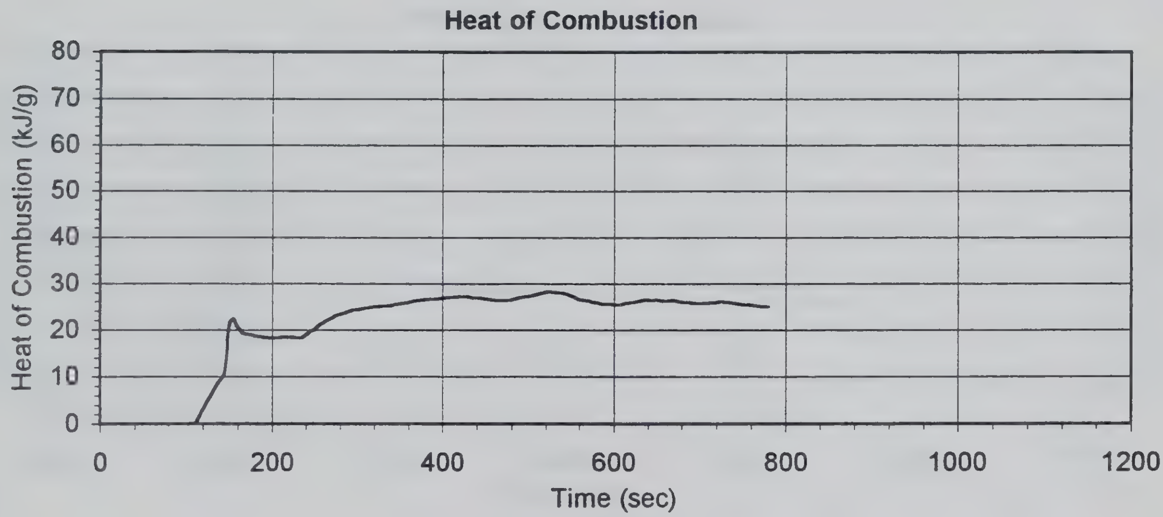


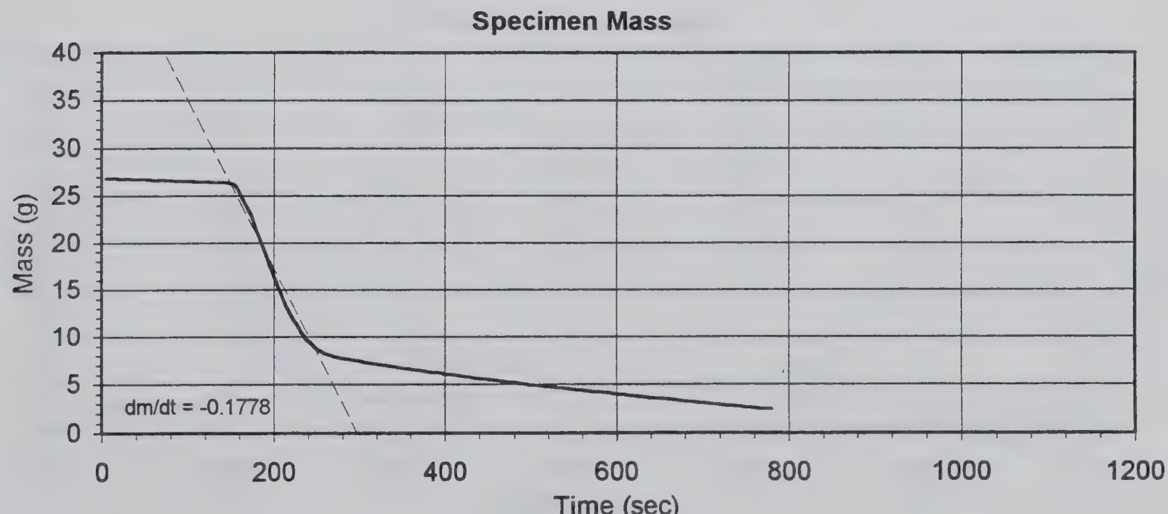




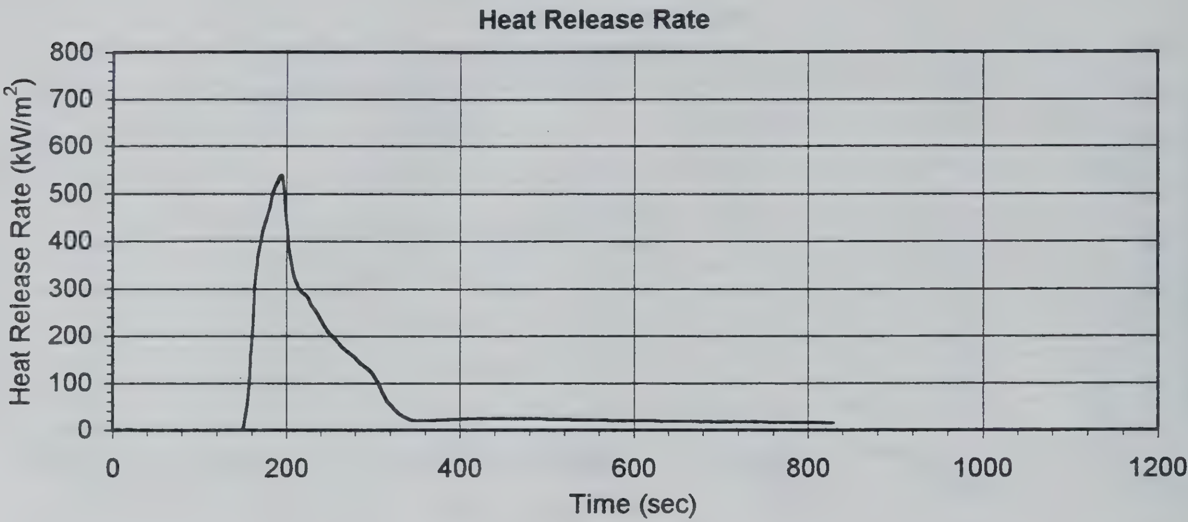
Cone Calorimeter Data R 4.08 3-Layered Polycarbonate Panel
40 kW/m^2, Test #2

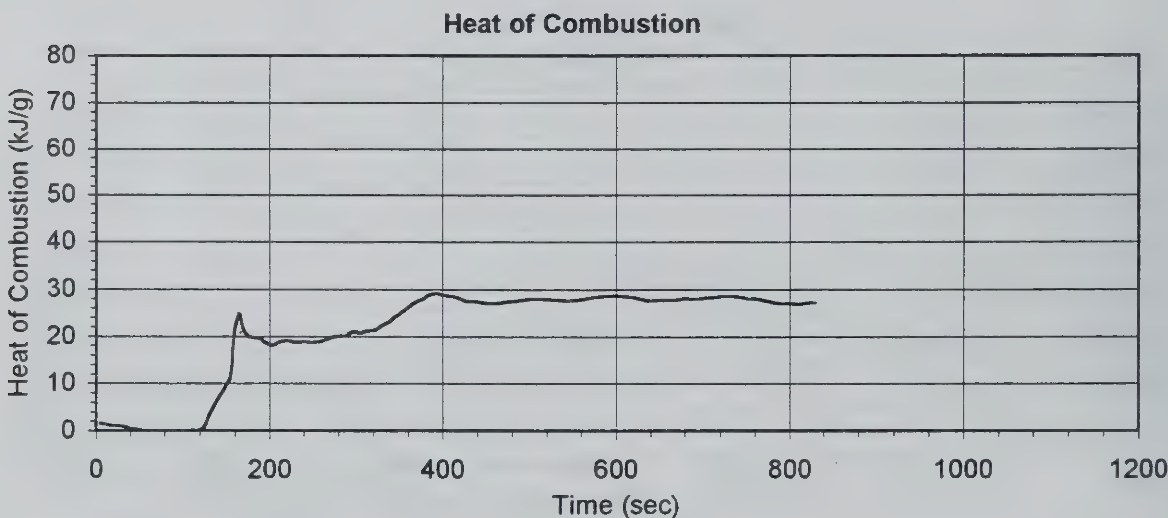


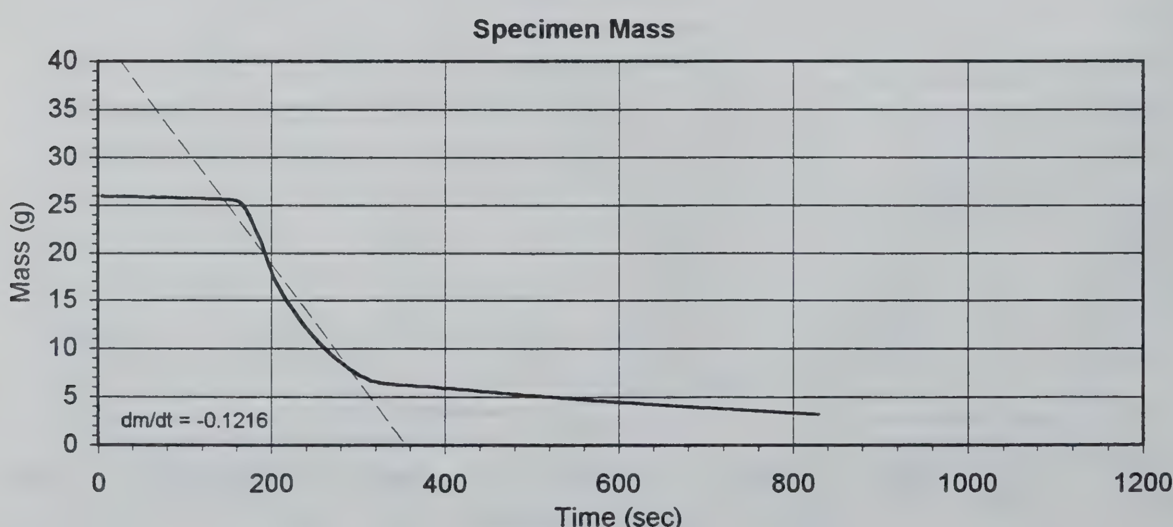




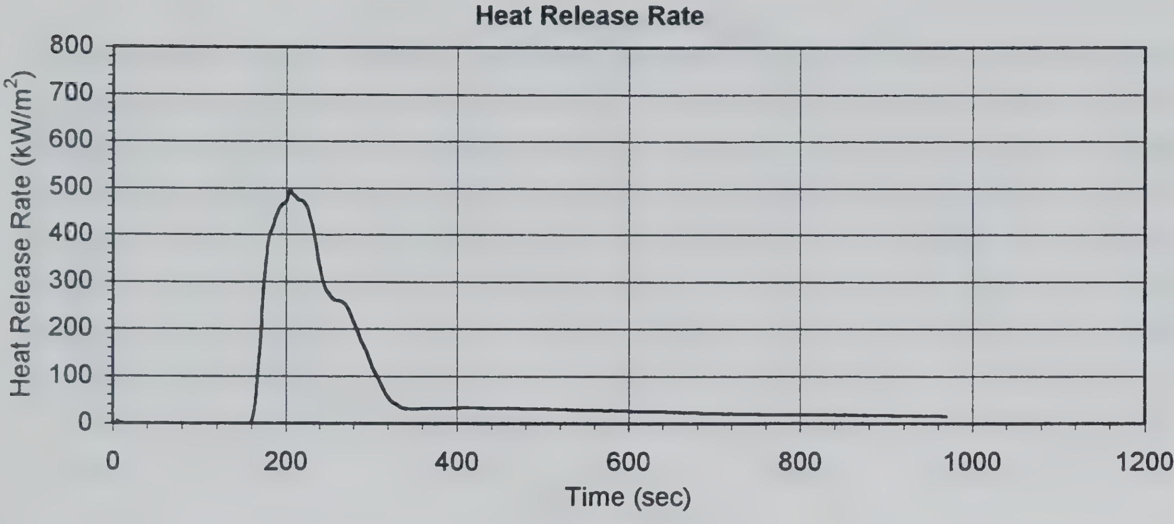
Cone Calorimeter Data R 4.08 3-Layered Polycarbonate Panel
40 kW/m^2, Test #3

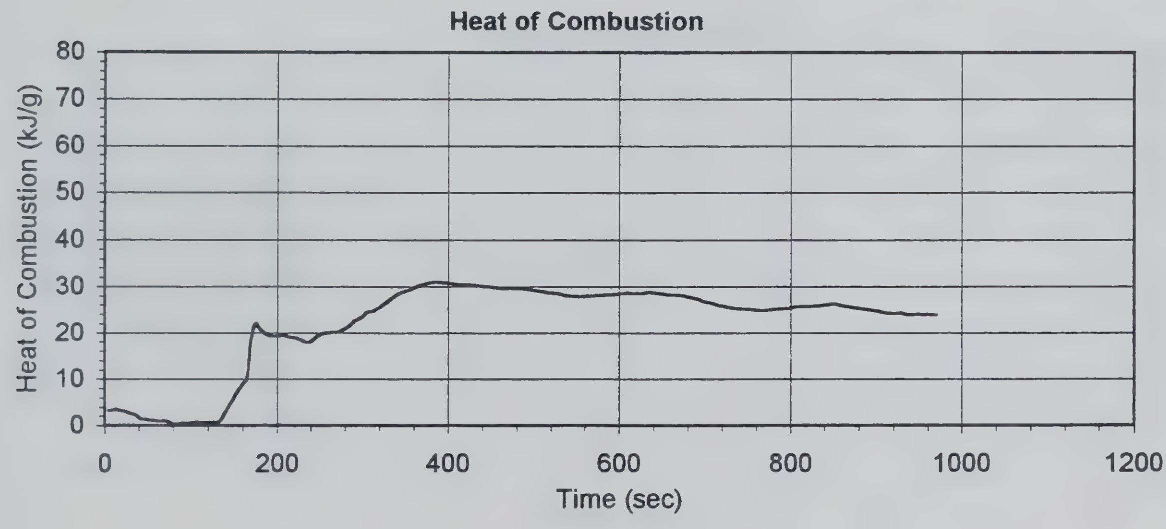


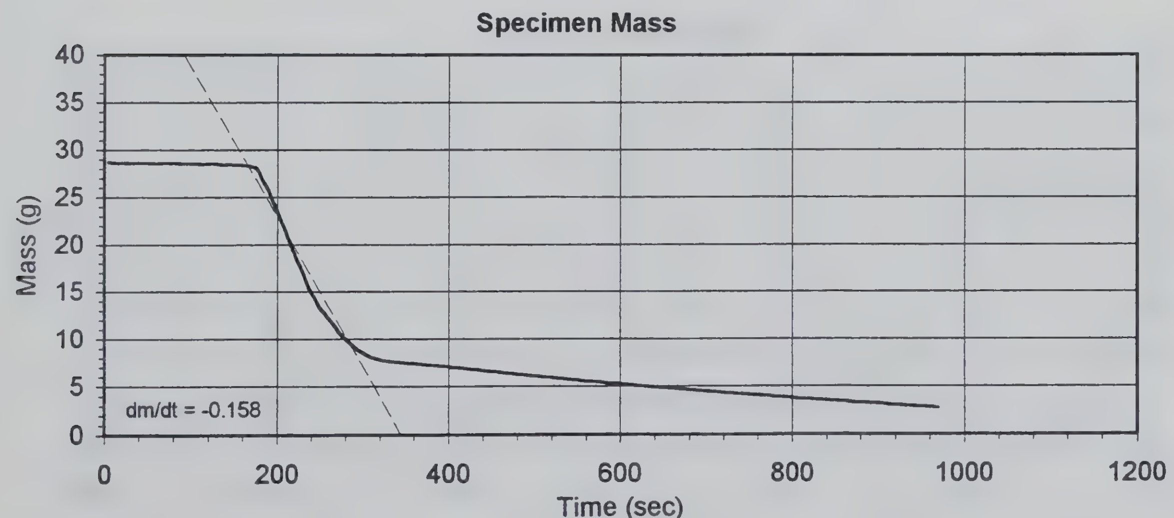




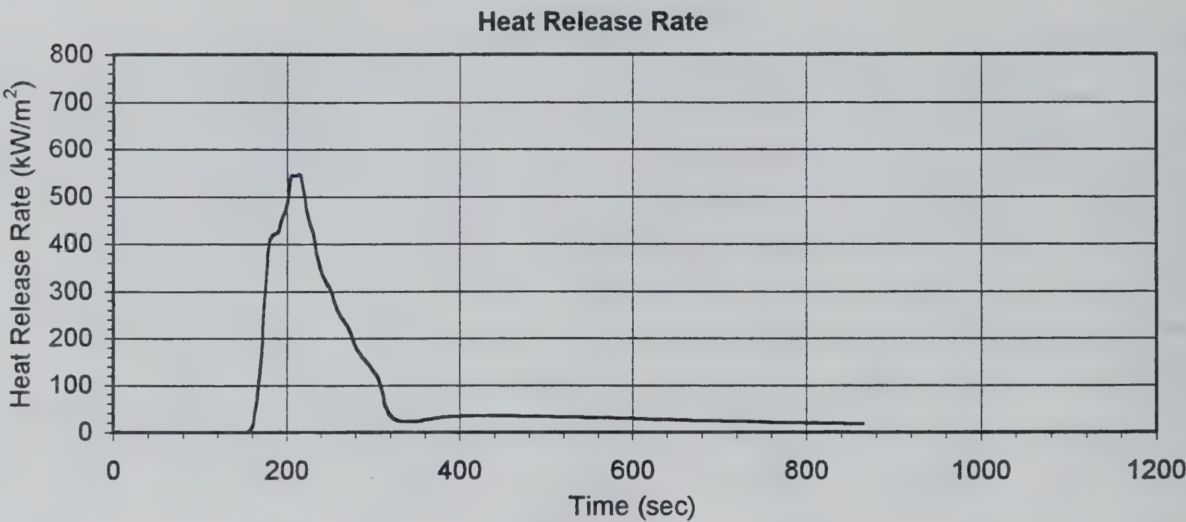
Cone Calorimeter Data R 4.08 3-Layered Polycarbonate Panel
40 kW/m^2, Test #4

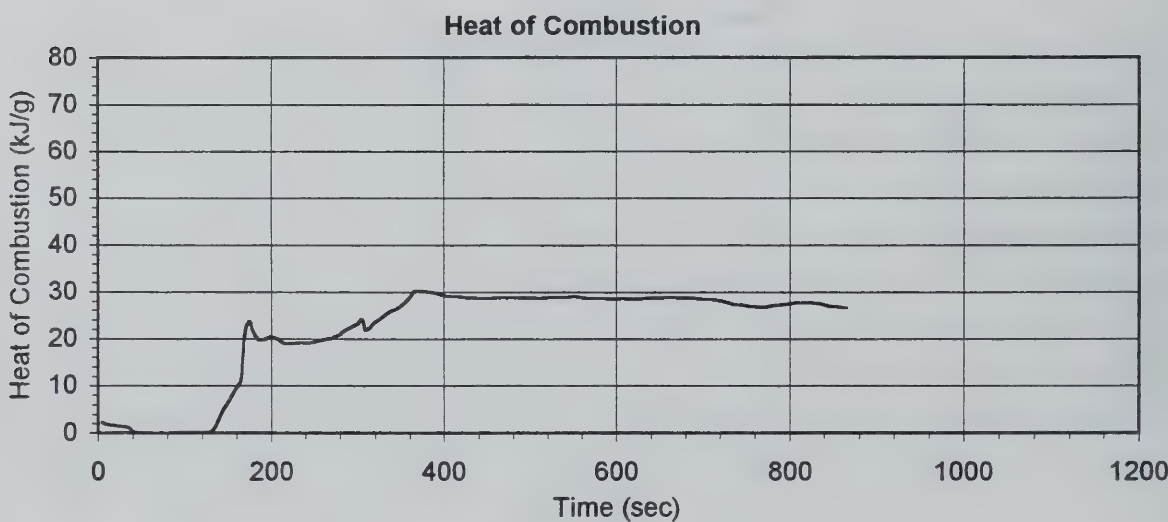


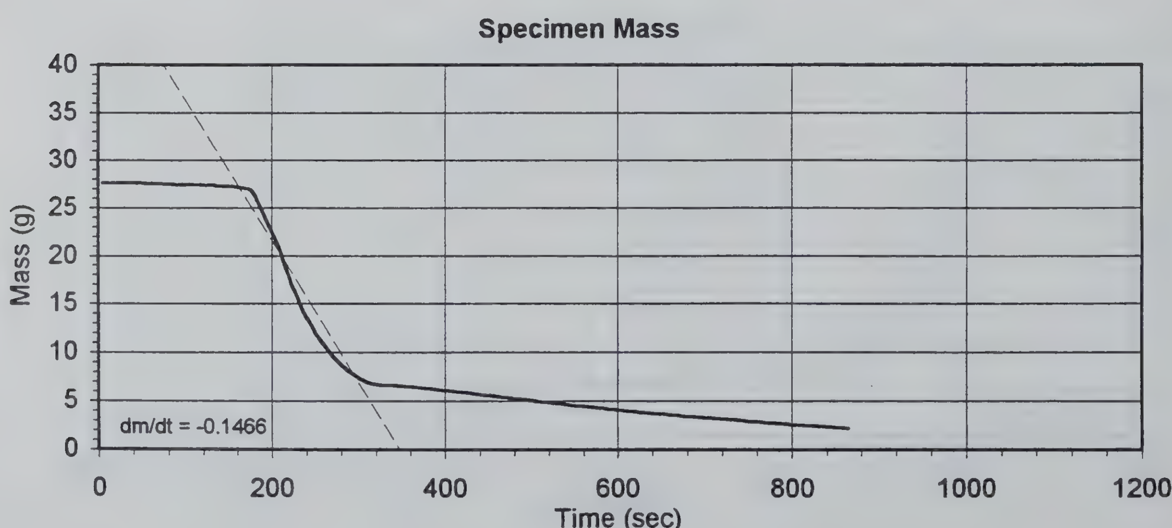




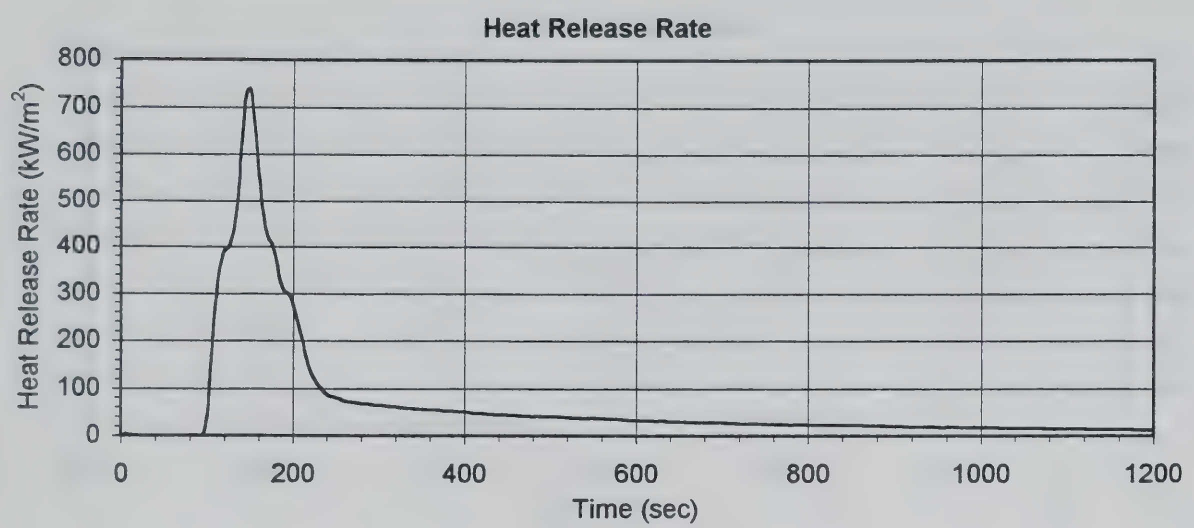
Cone Calorimeter Data R 4.08 3-Layered Polycarbonate Panel
40 kW/m^2, Test #5

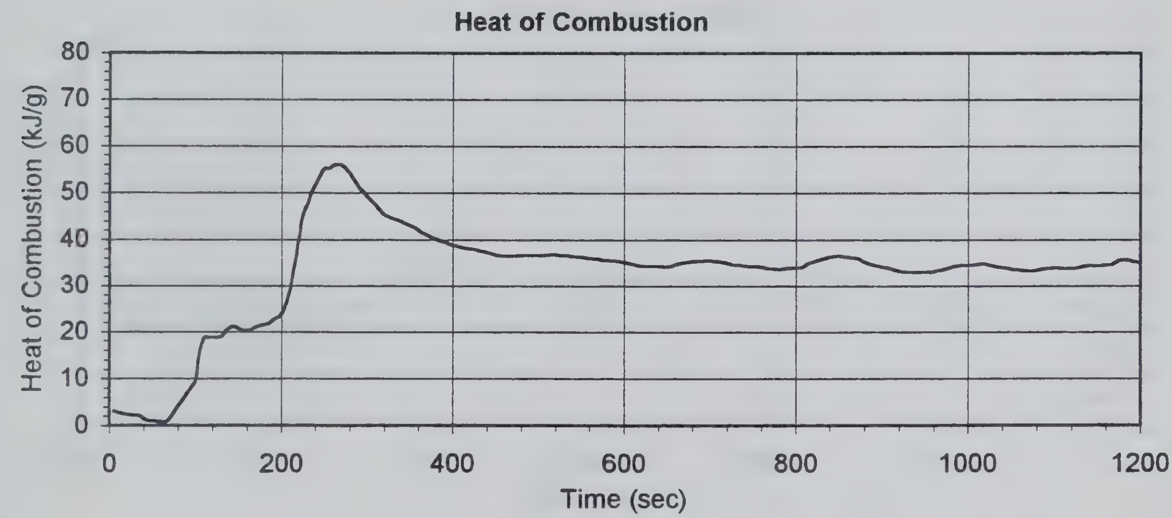


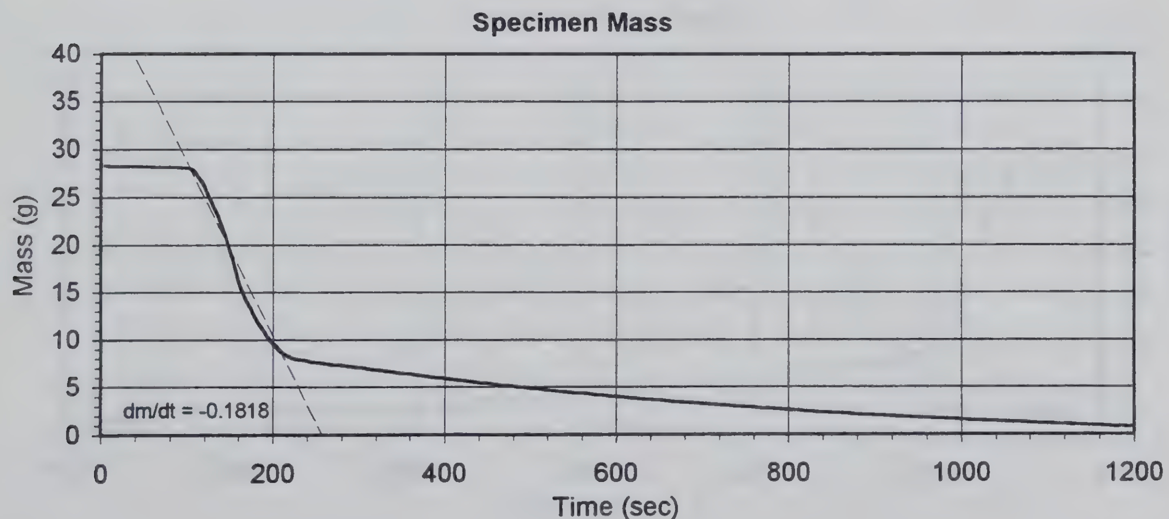




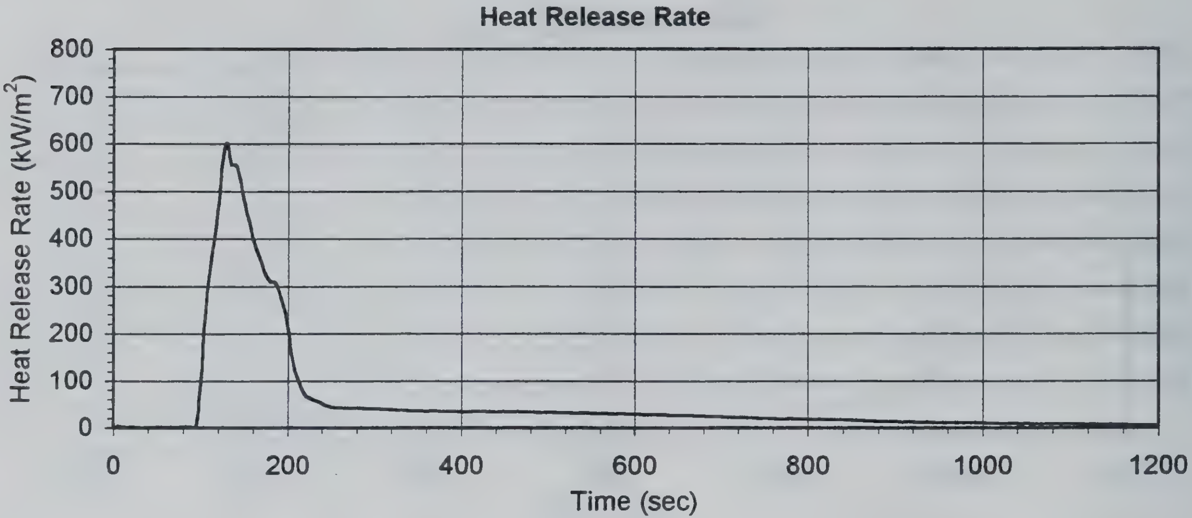
Cone Calorimeter Data R 4.08 3-Layered Polycarbonate Panel
50 kW/m^2, Test #1

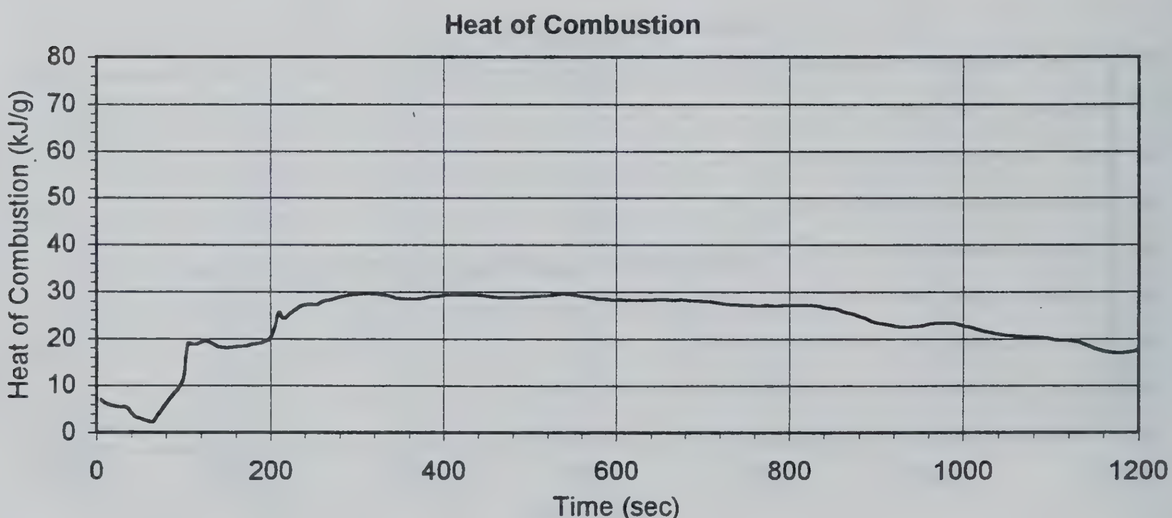


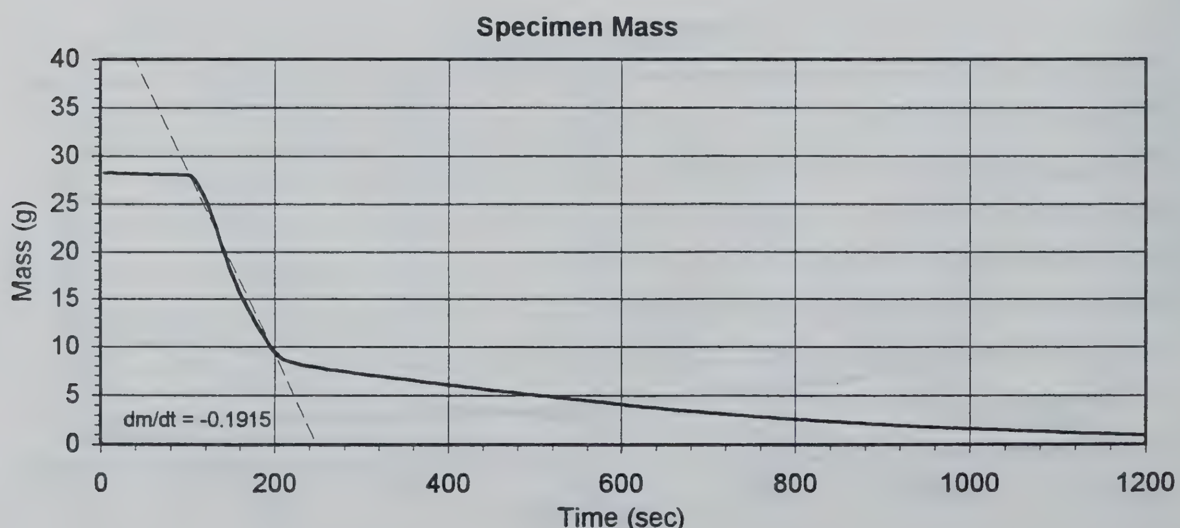




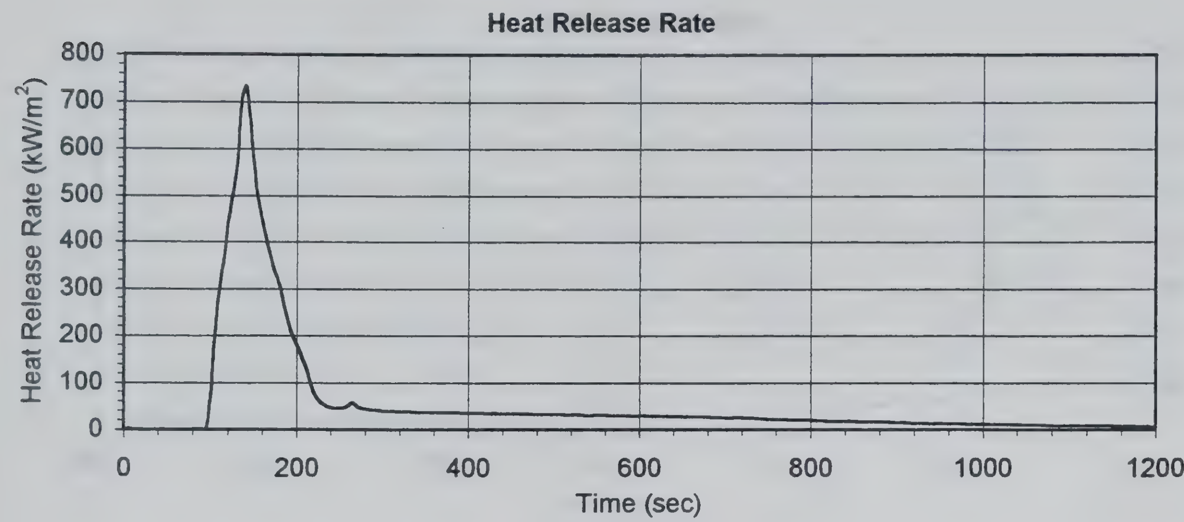
Cone Calorimeter Data R 4.08 3-Layered Polycarbonate Panel
50 kW/m², Test #2

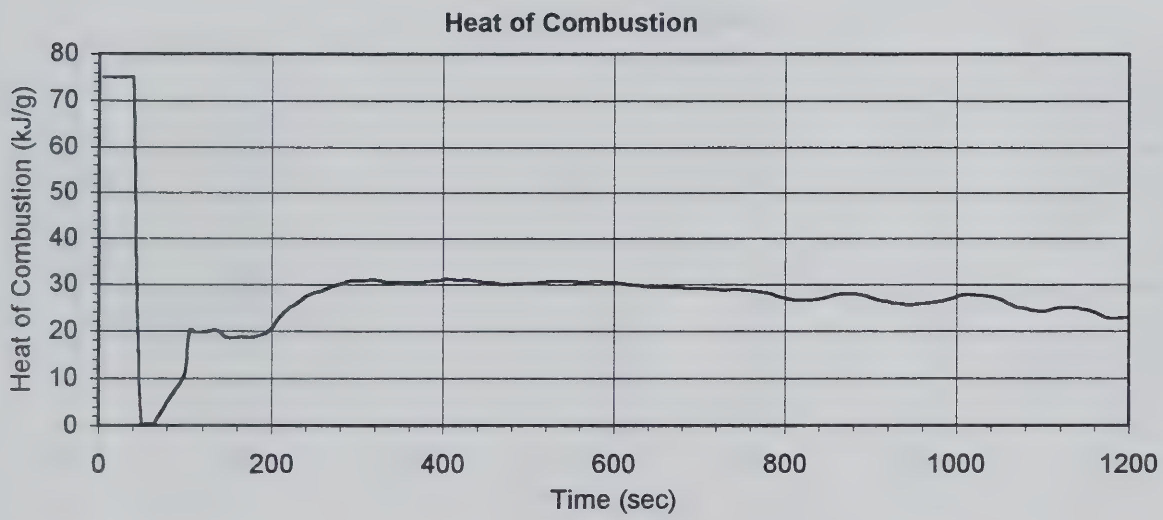


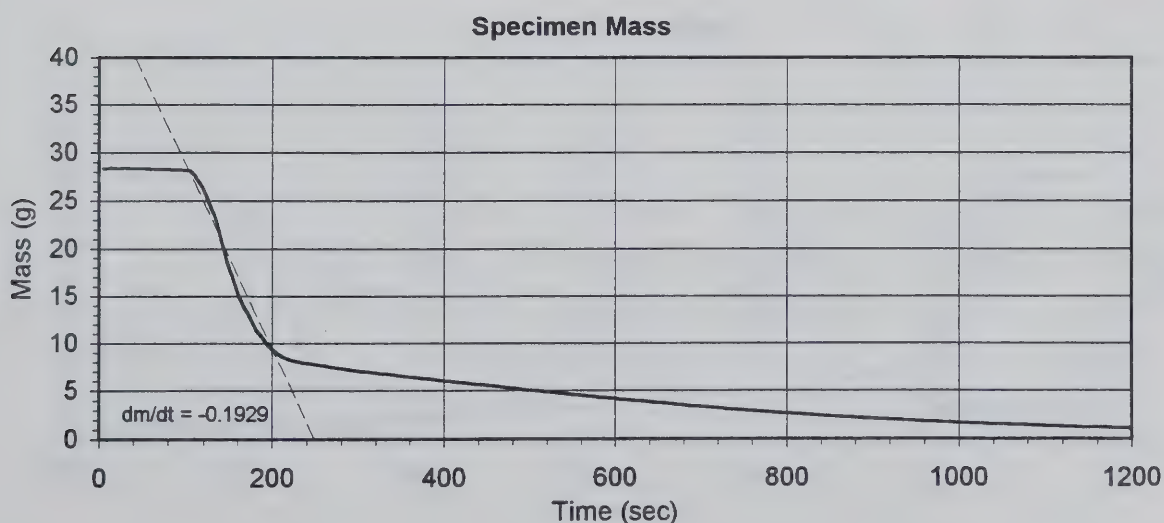




Cone Calorimeter Data R 4.08 3-Layered Polycarbonate Panel
50 kW/m^2, Test #3







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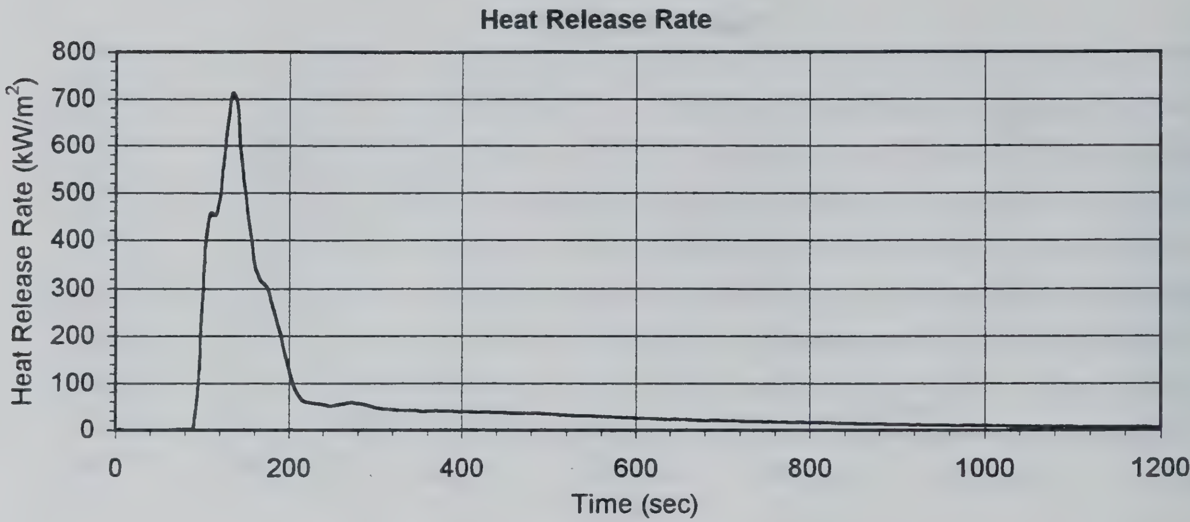
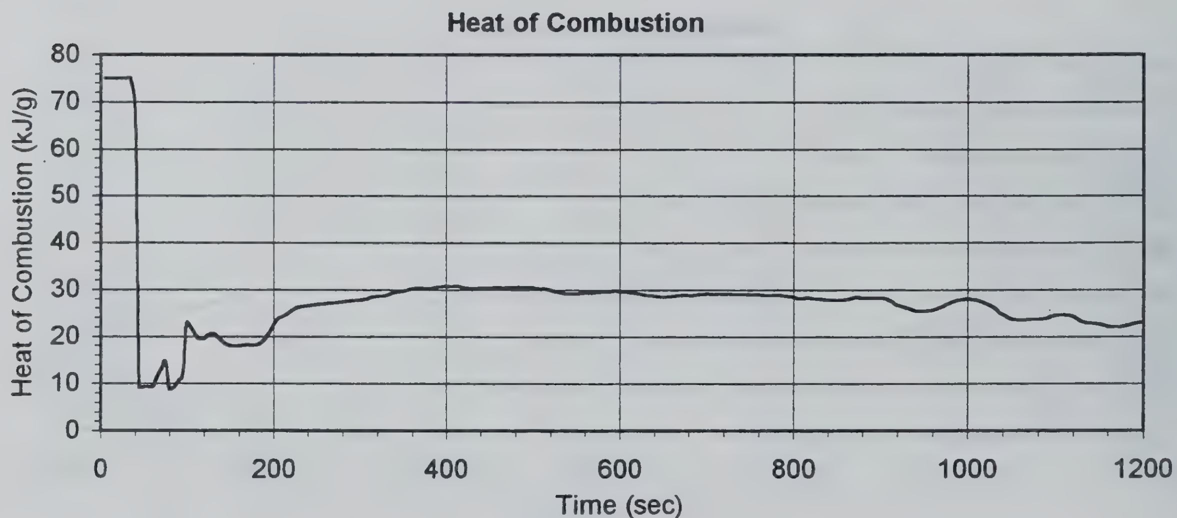
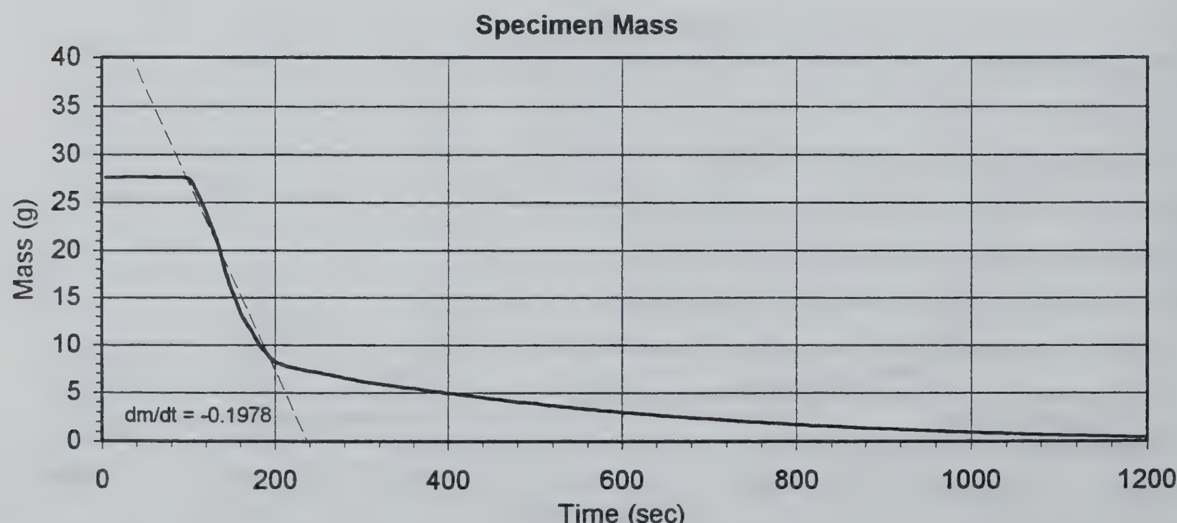
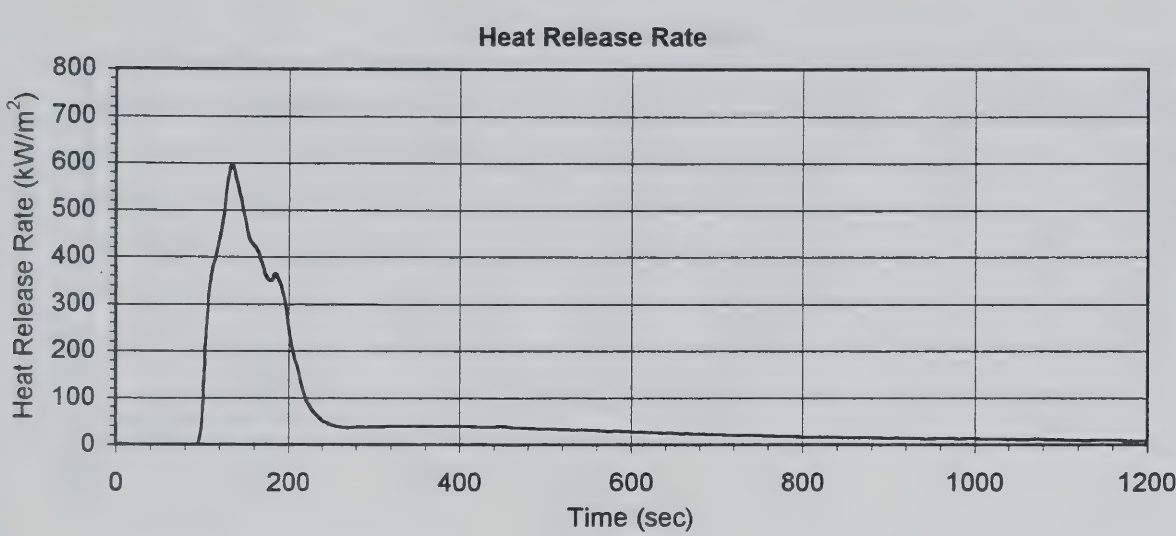
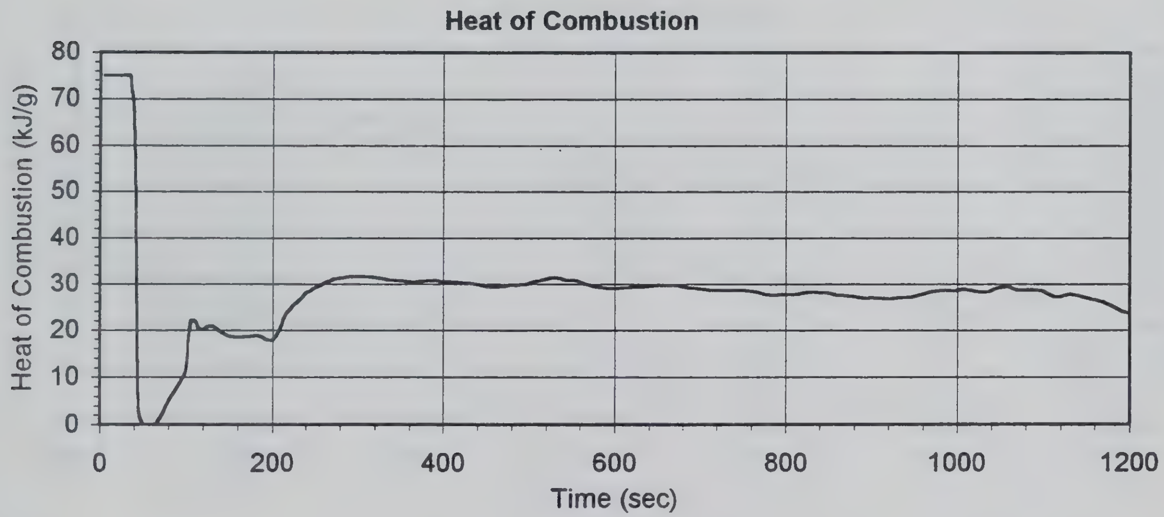


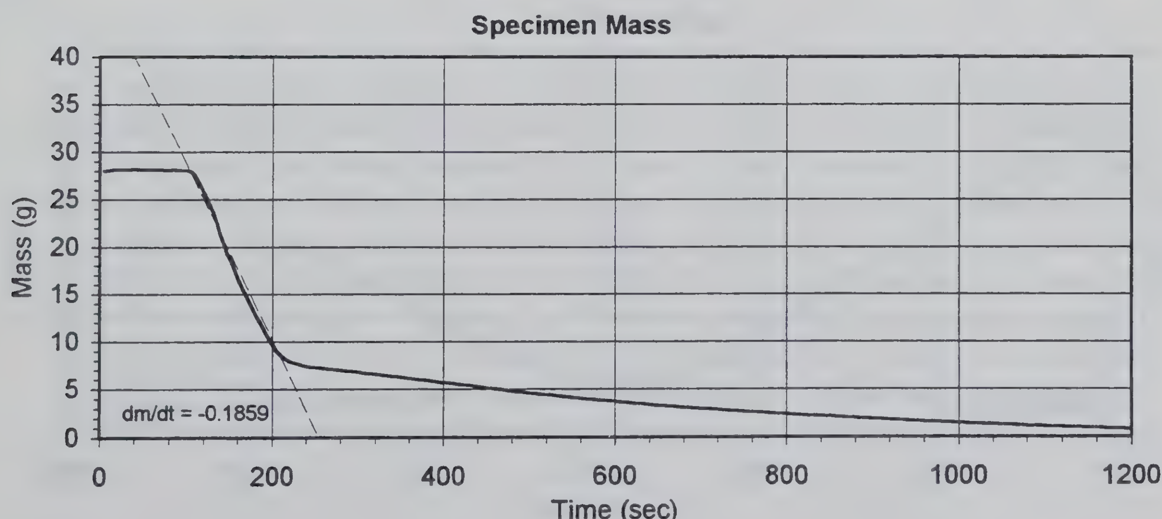




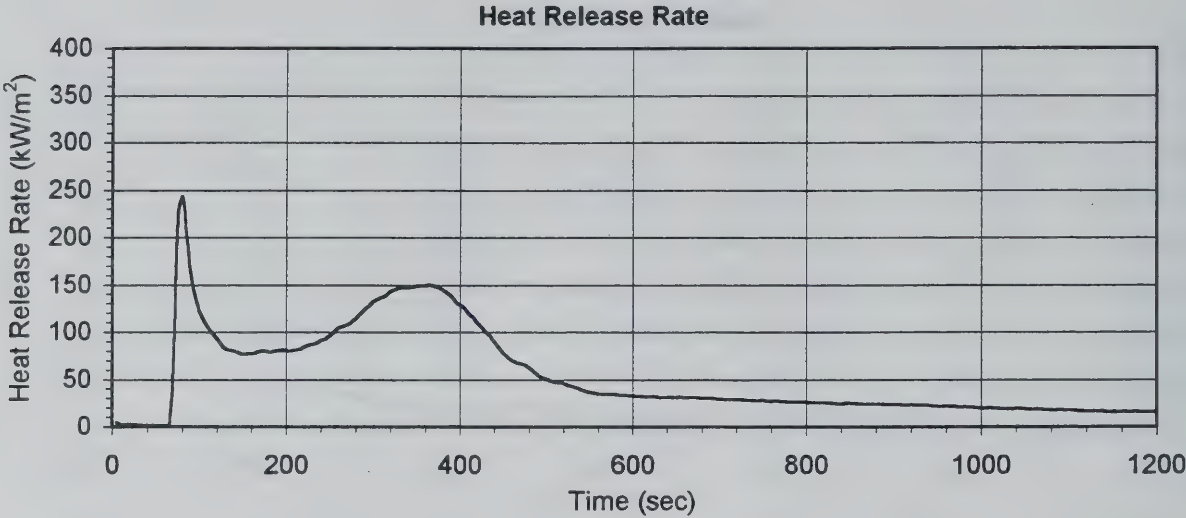
Cone Calorimeter Data R 4.08 3-Layered Polycarbonate Panel
50 kW/m^2, Test #5

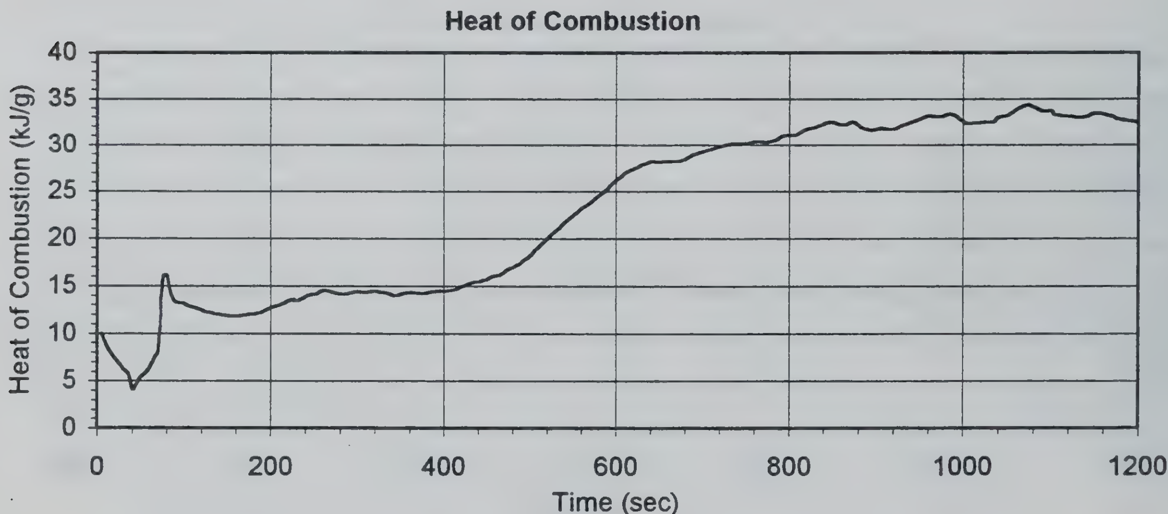


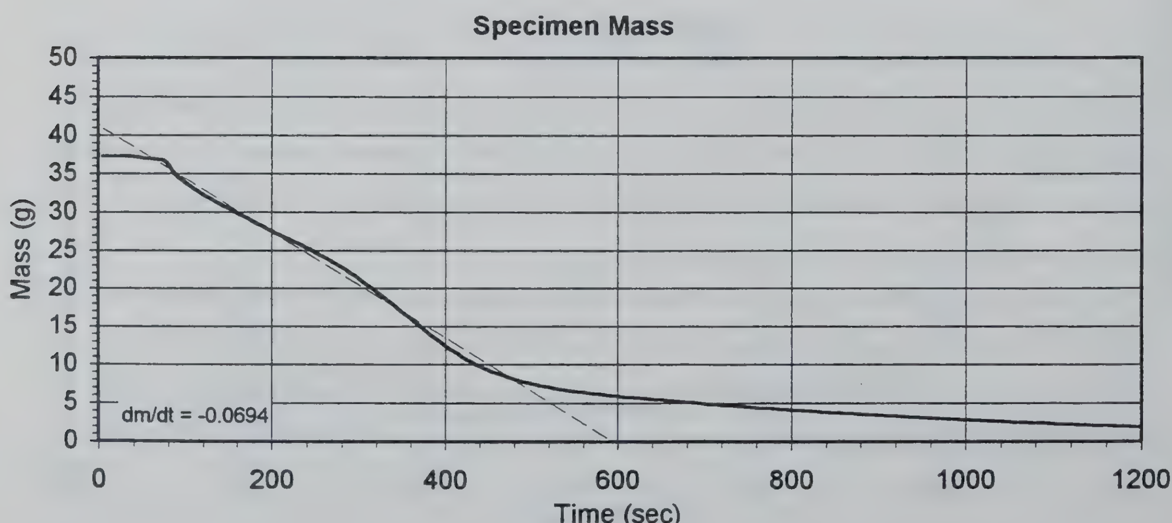




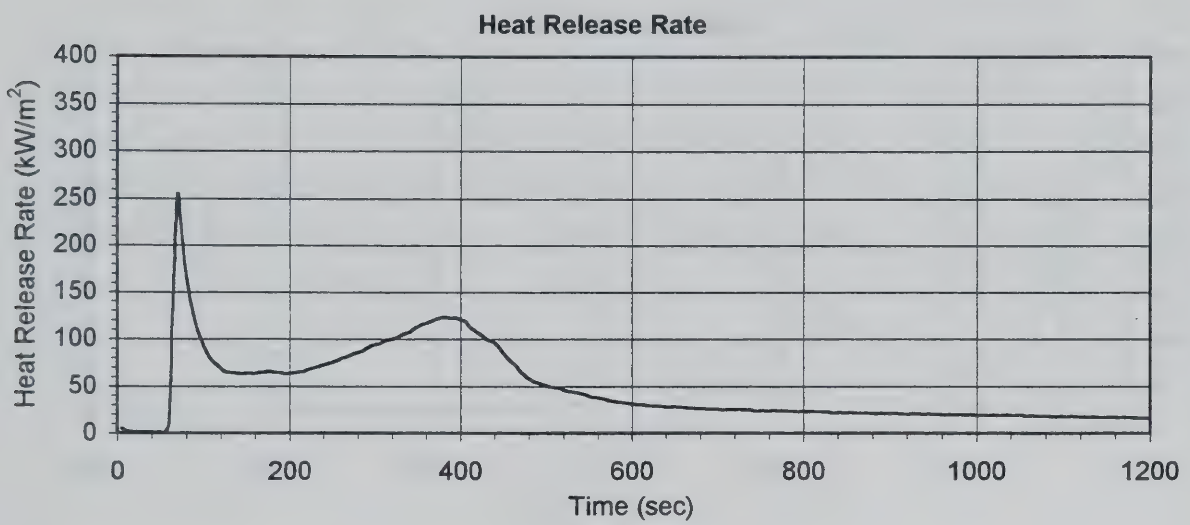
Cone Calorimeter Data R 4.09 Varnished Massive Timber
25 kW/m^2, Test #1

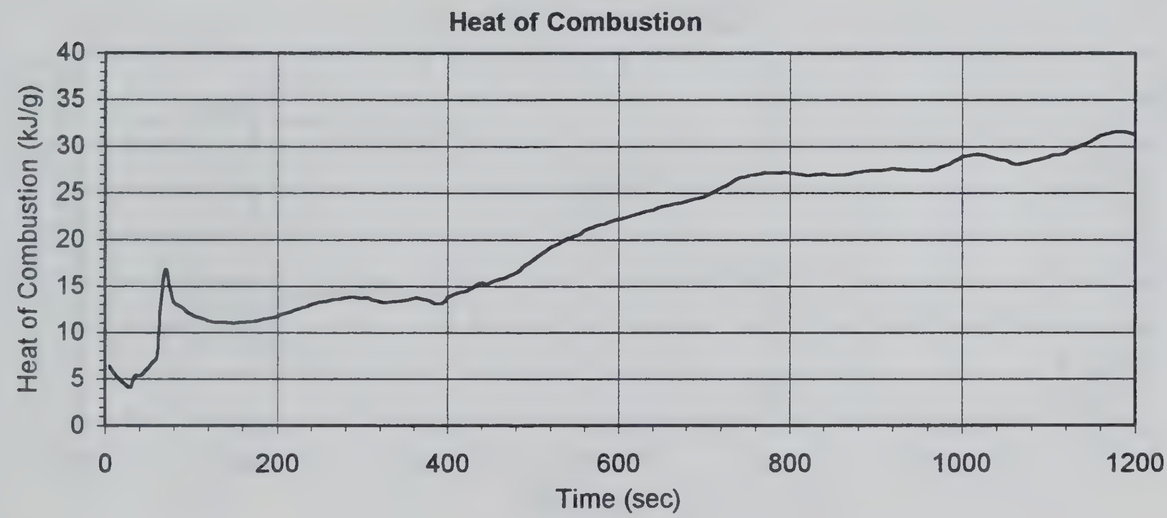


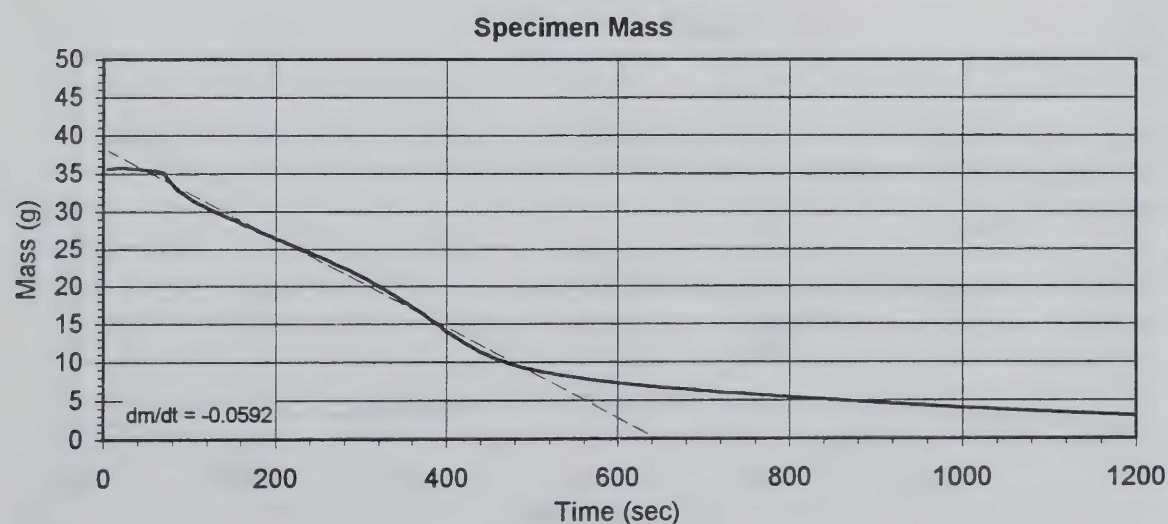




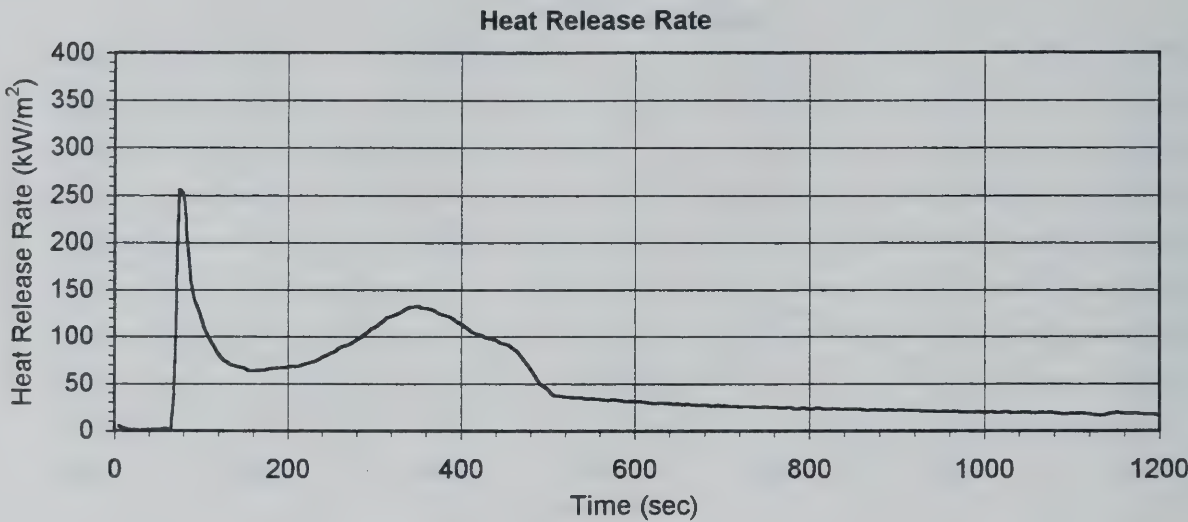
Cone Calorimeter Data R 4.09 Varnished Massive Timber
25 kW/m², Test #2

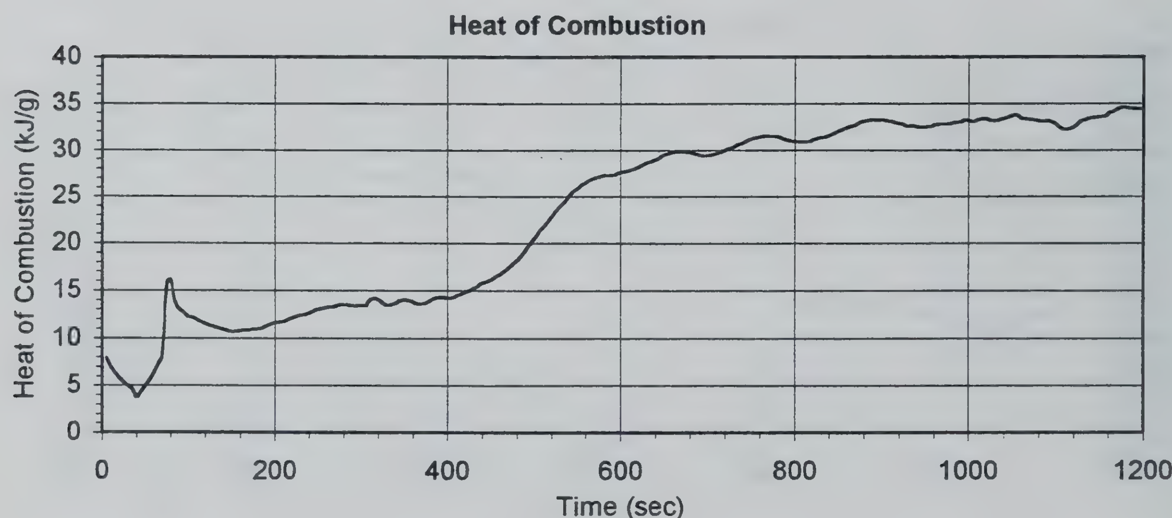


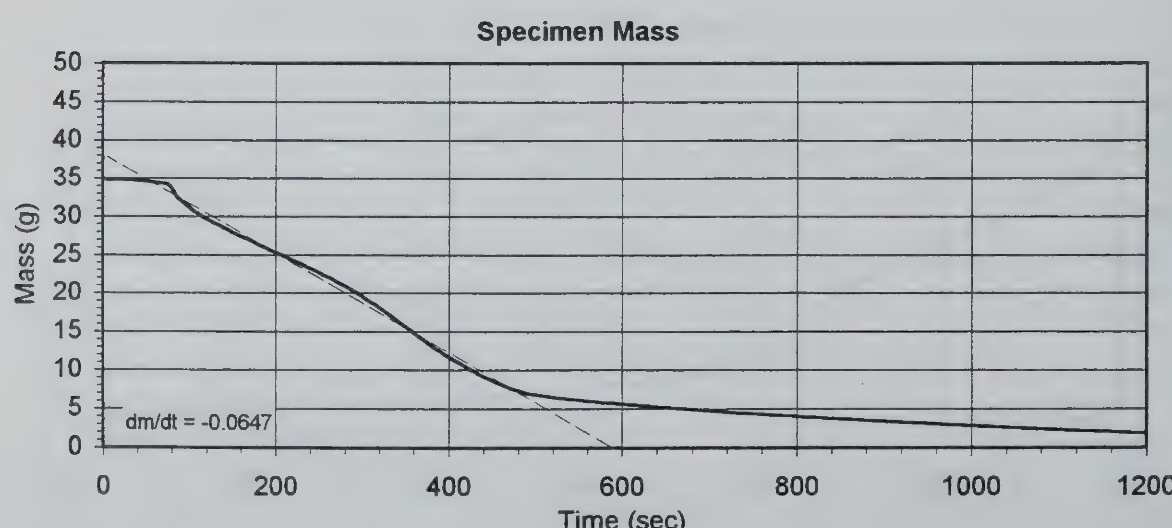




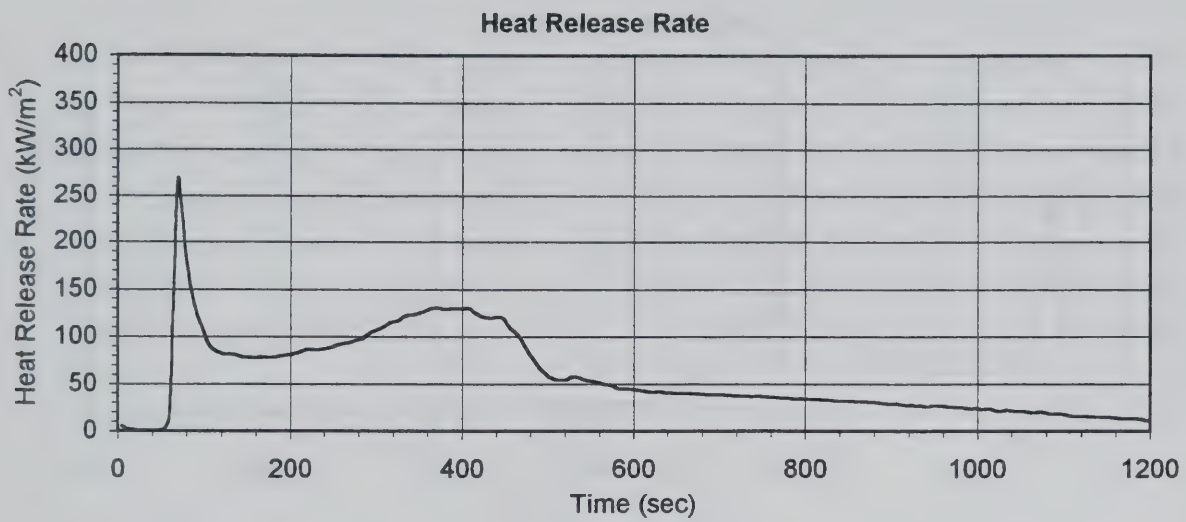
Cone Calorimeter Data R 4.09 Varnished Massive Timber
25 kW/m^2, Test #3

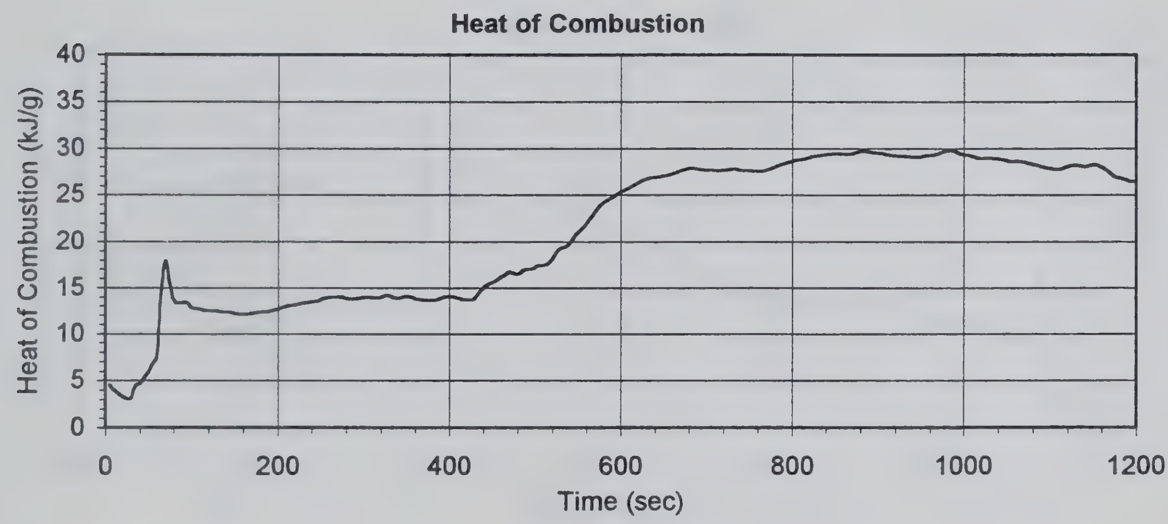


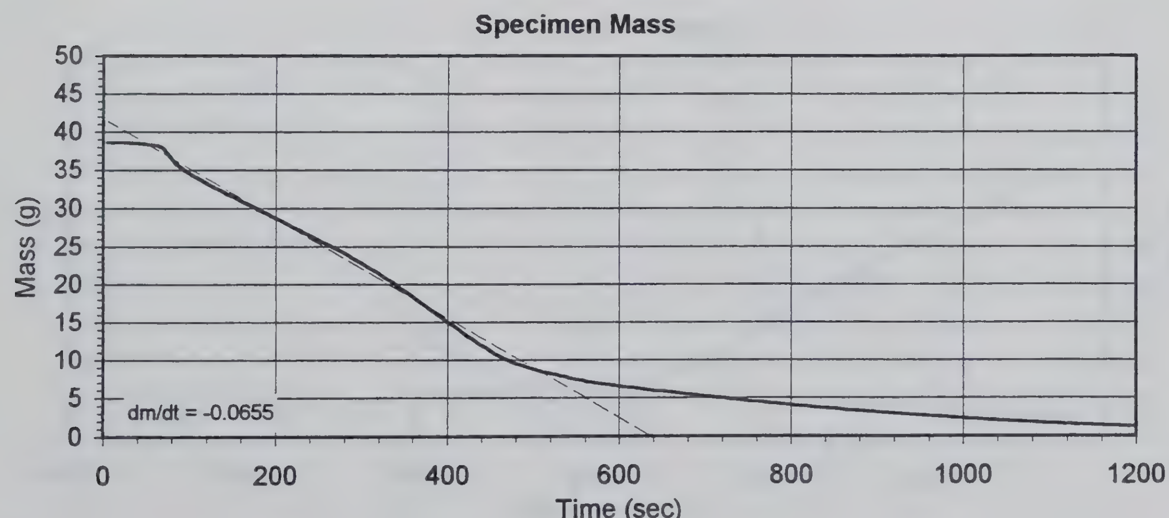




Cone Calorimeter Data R 4.09 Varnished Massive Timber
25 kW/m², Test #4

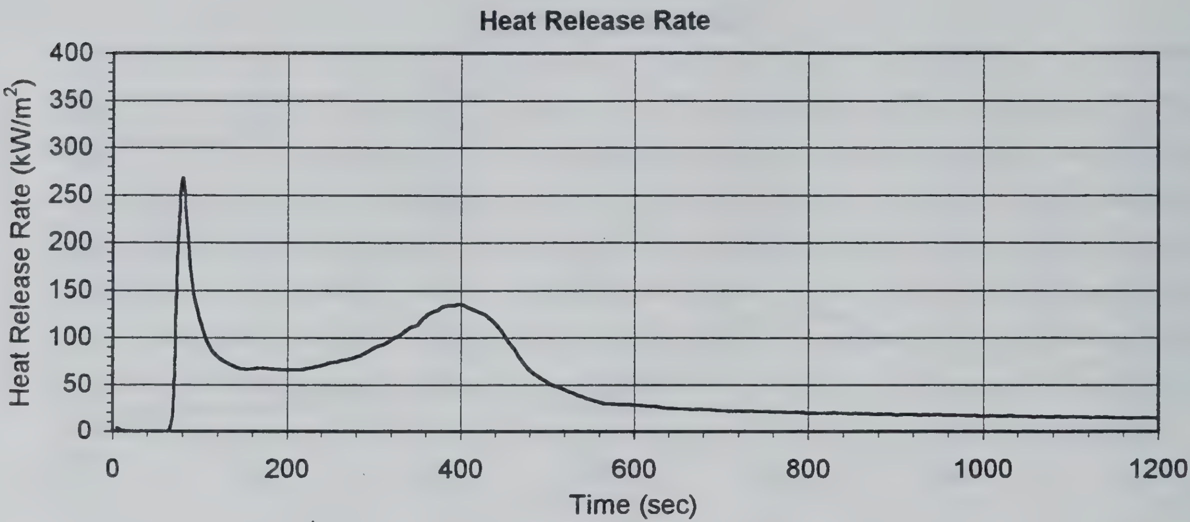


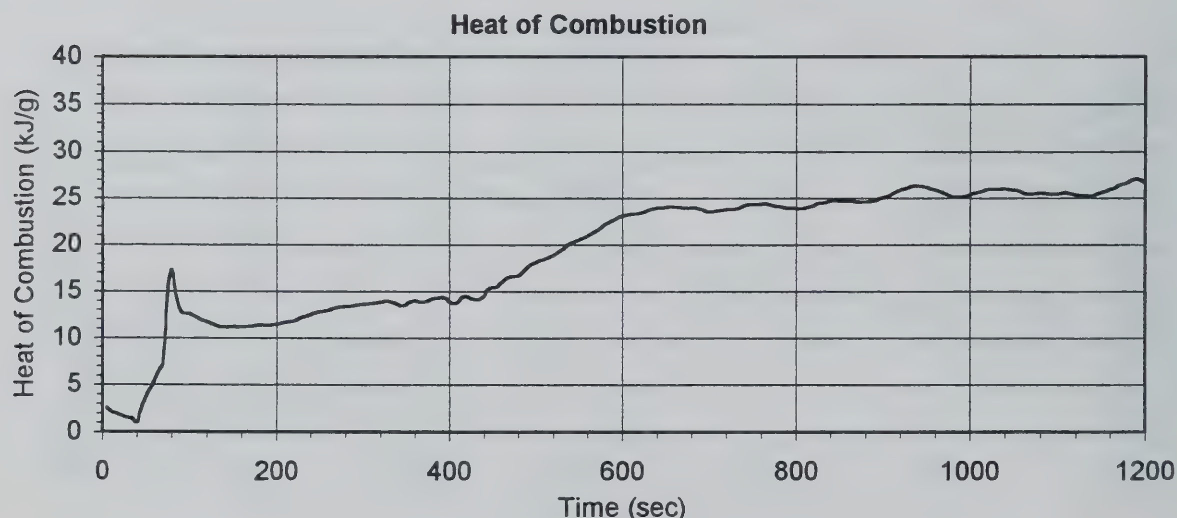


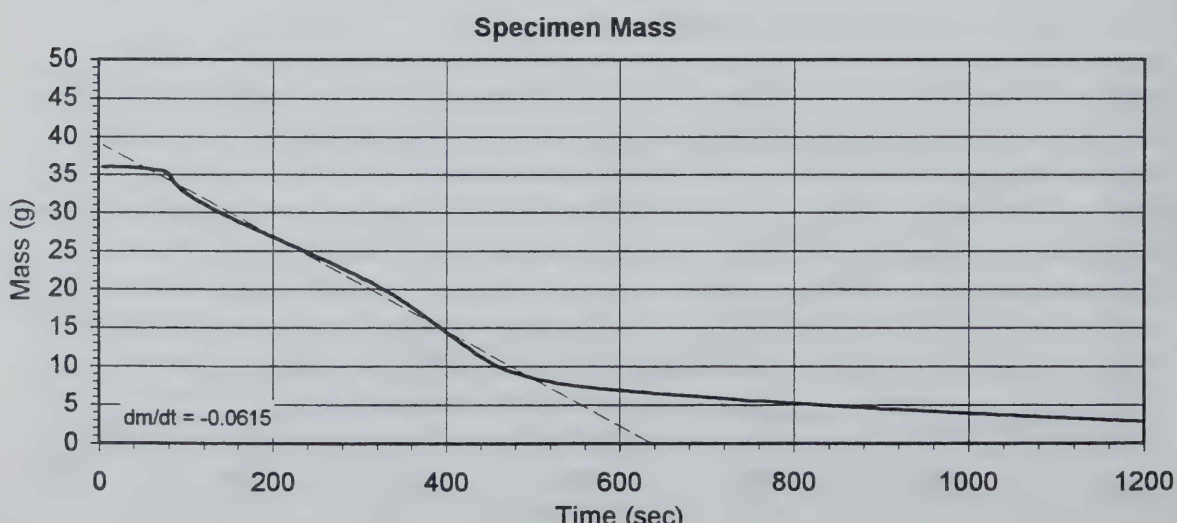


Cone Calorimeter Data R 4.09 Varnished Massive Timber

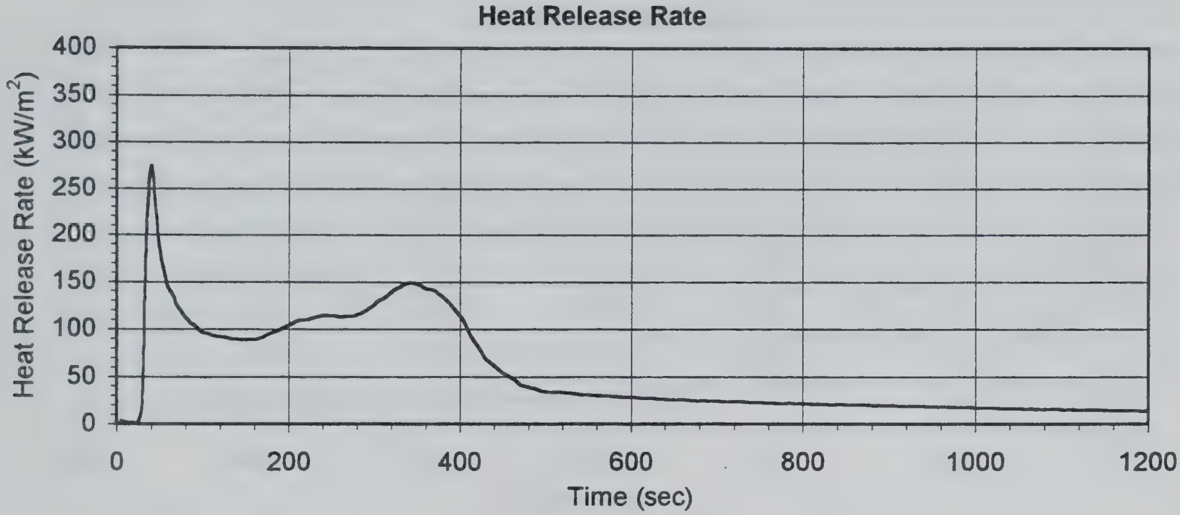
25 kW/m^2, Test #5

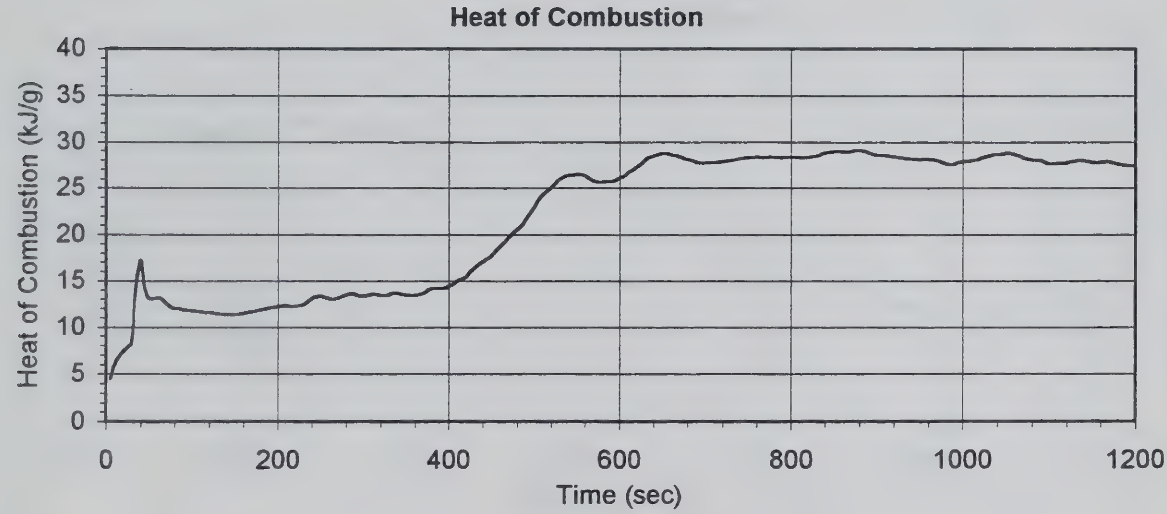


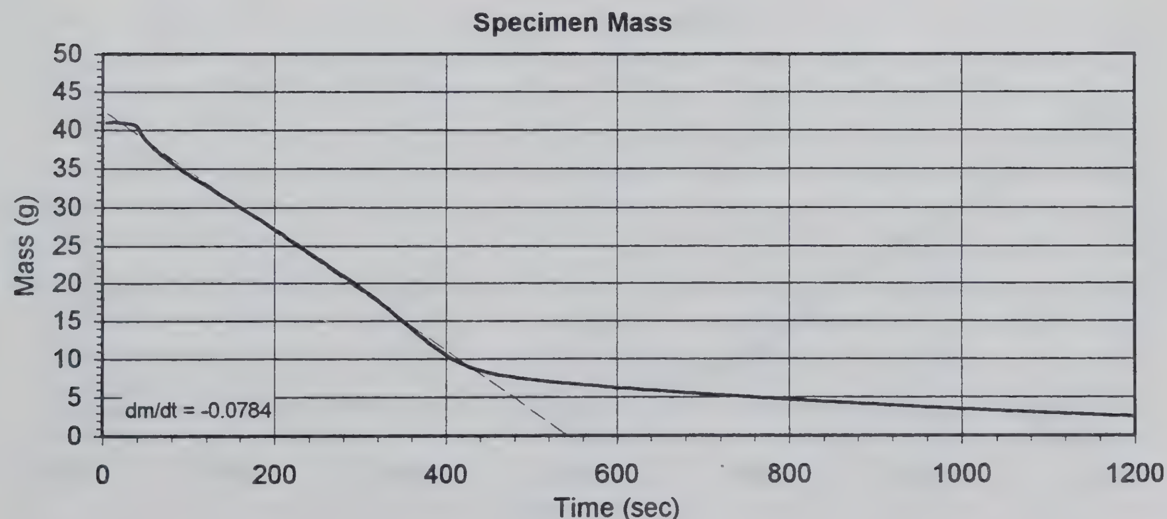




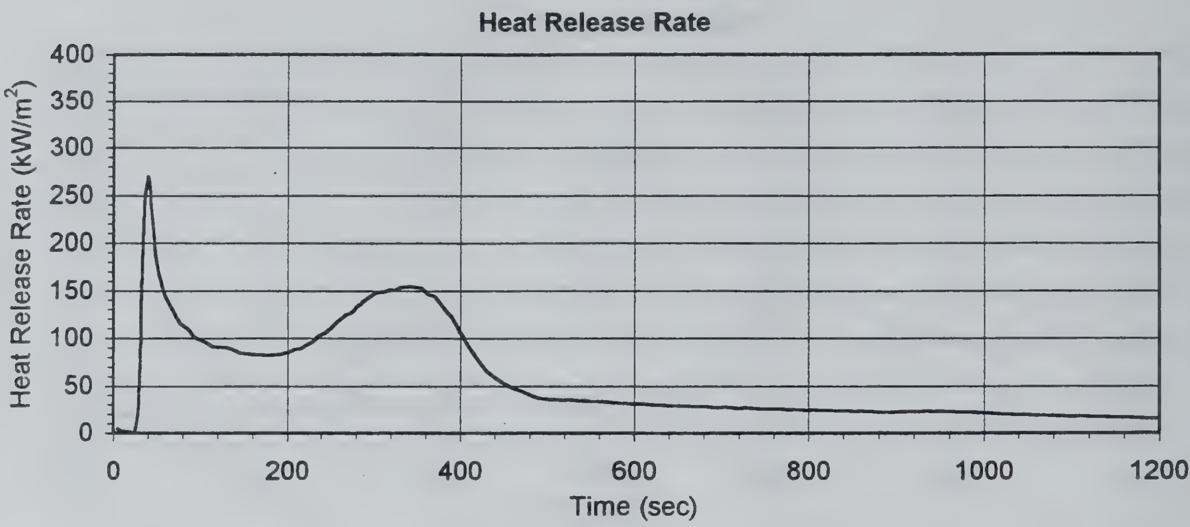
Cone Calorimeter Data R 4.09 Varnished Massive Timber
35 kW/m^2, Test #1

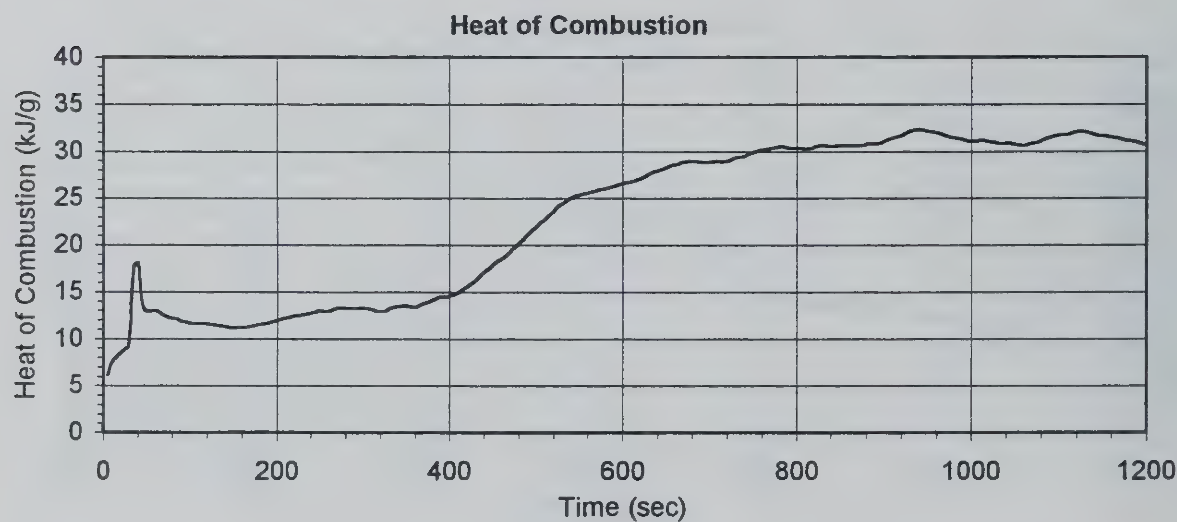


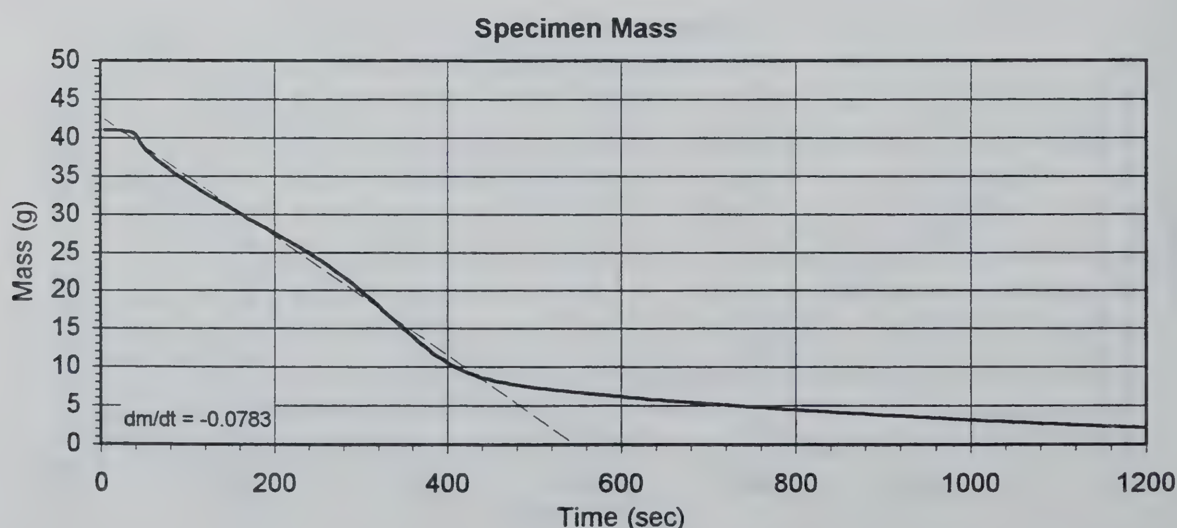




Cone Calorimeter Data R 4.09 Varnished Massive Timber
35 kW/m^2, Test #2







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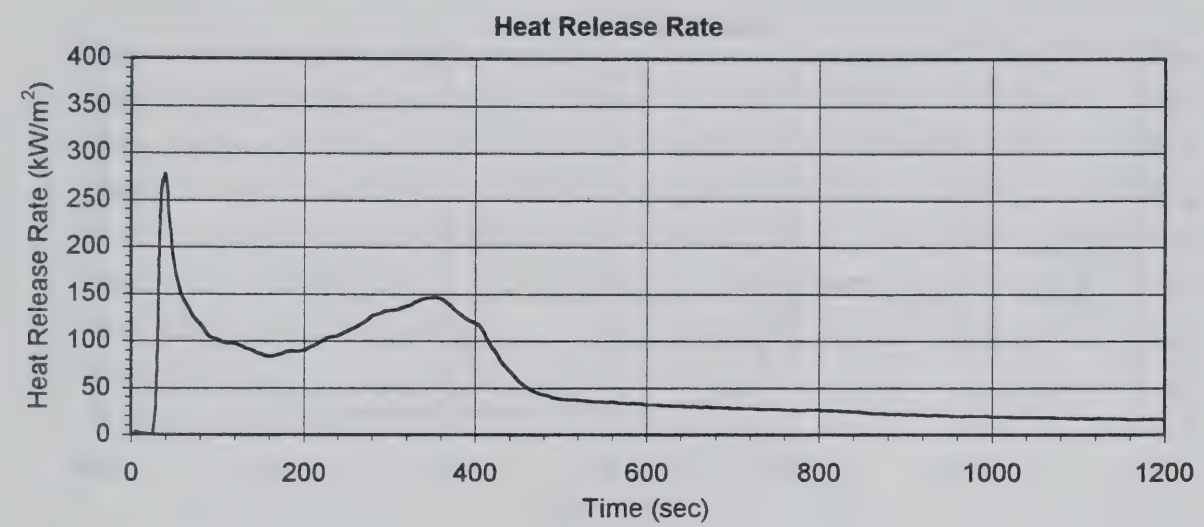
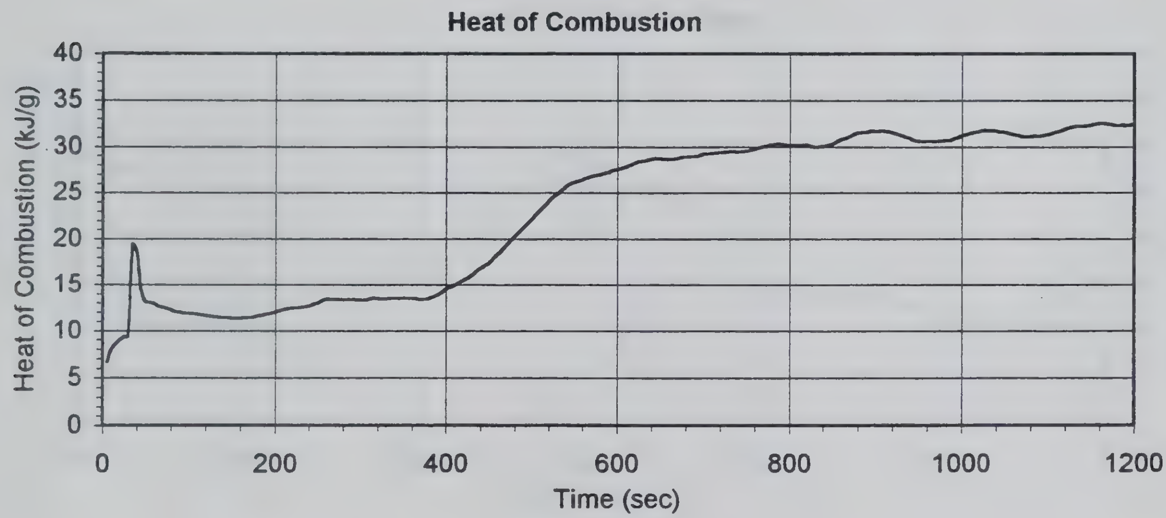
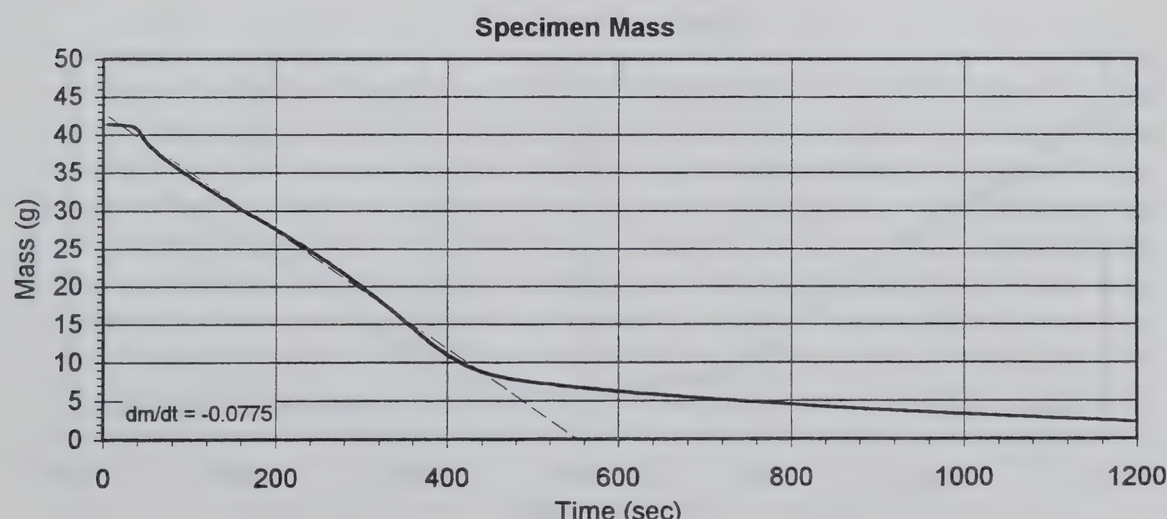
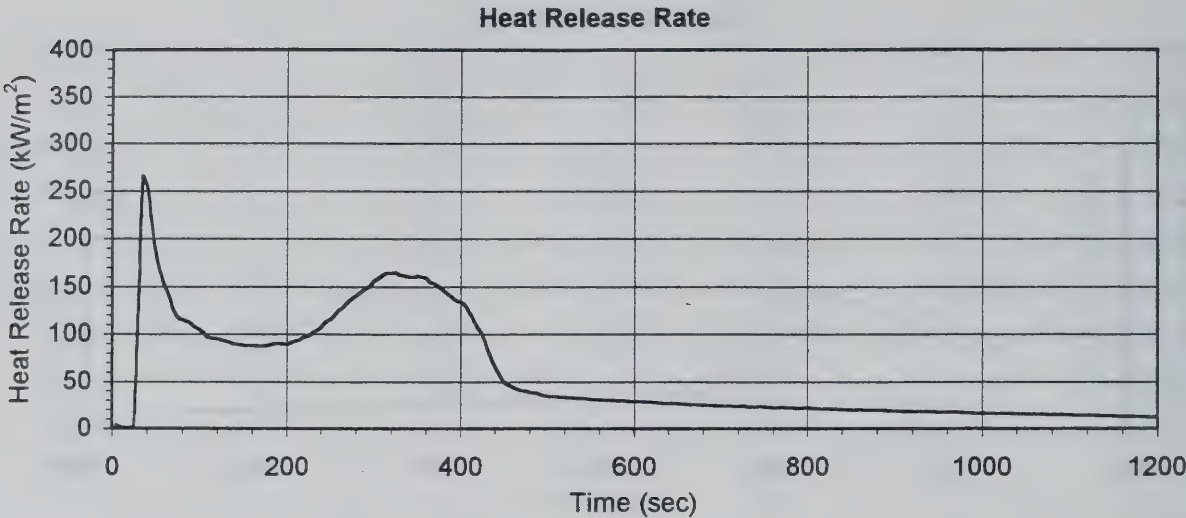
35 kW/m^2, Test #3

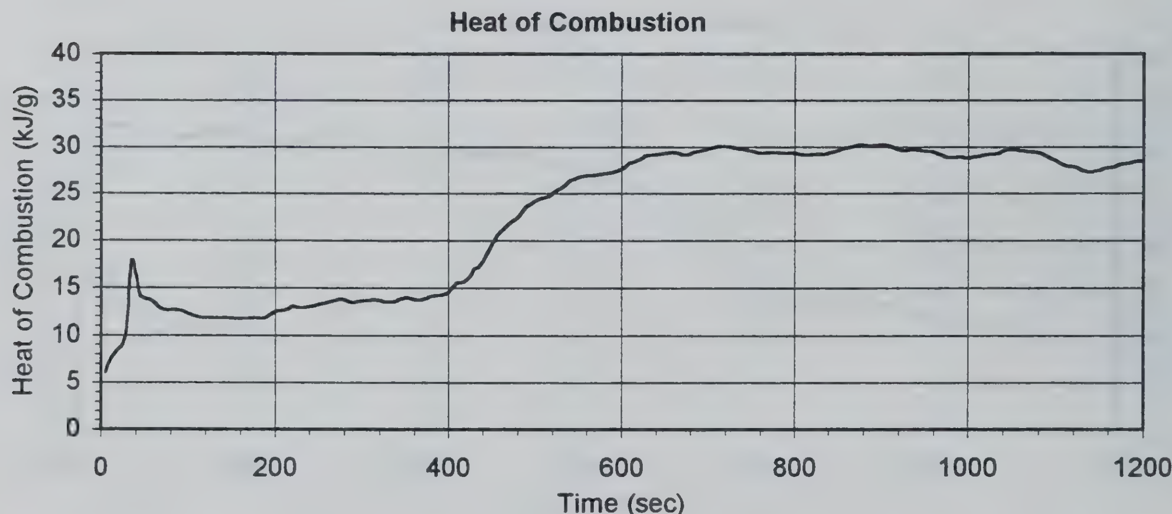


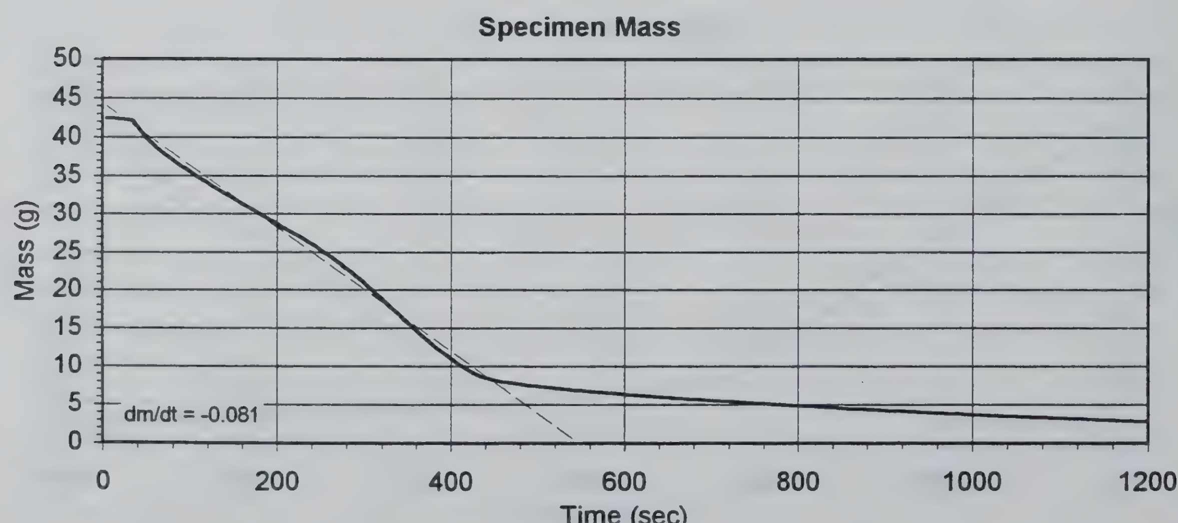




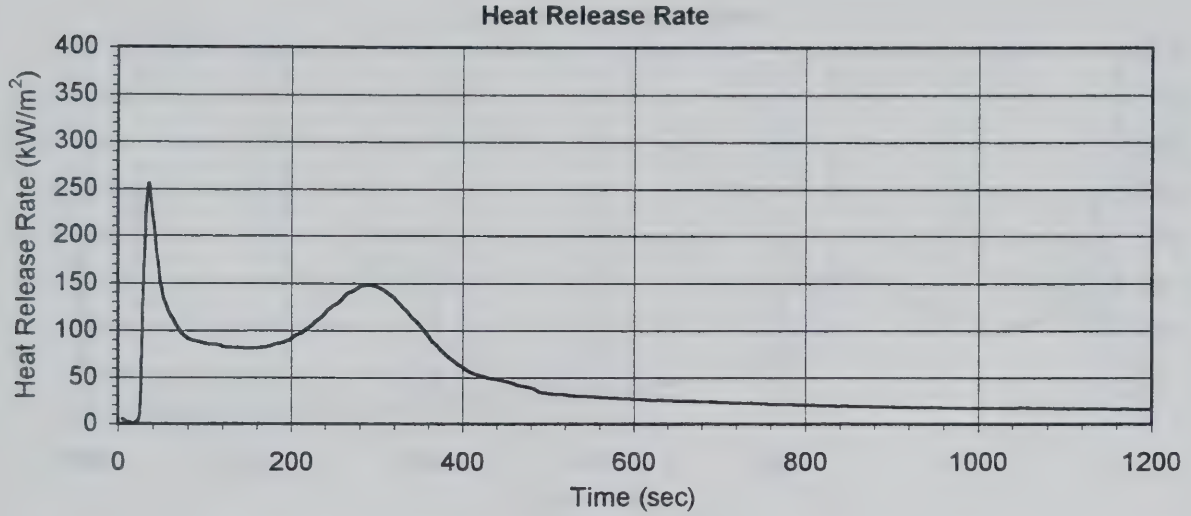
Cone Calorimeter Data R 4.09 Varnished Massive Timber
35 kW/m², Test #4

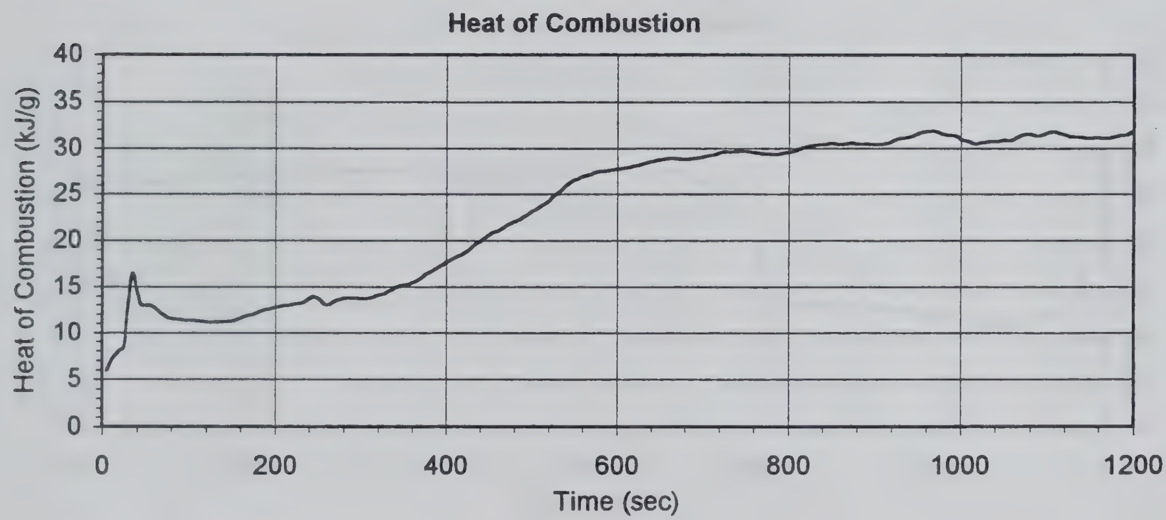


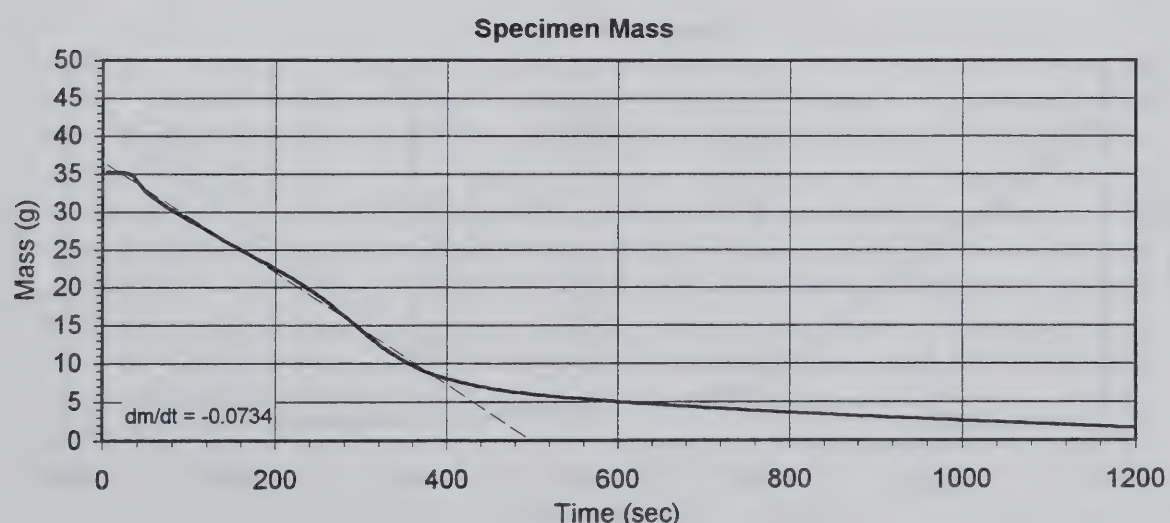




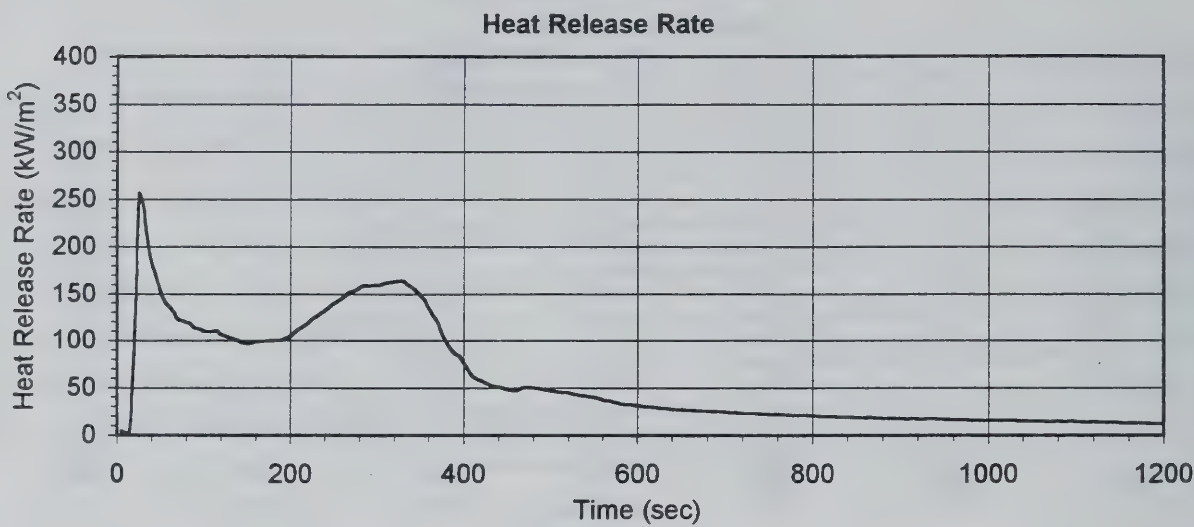
Cone Calorimeter Data R 4.09 Varnished Massive Timber
35 kW/m^2, Test #5

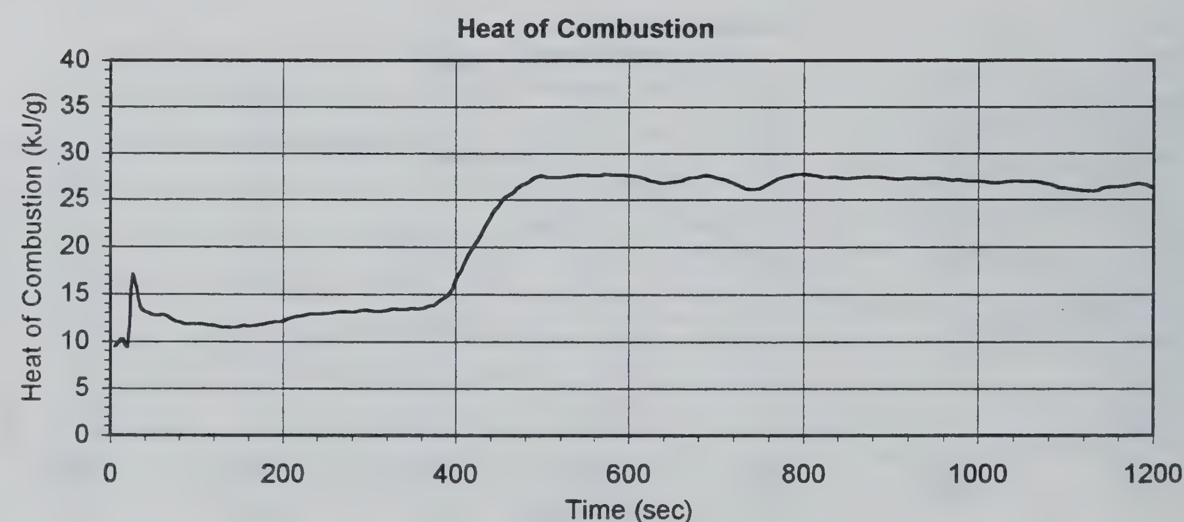


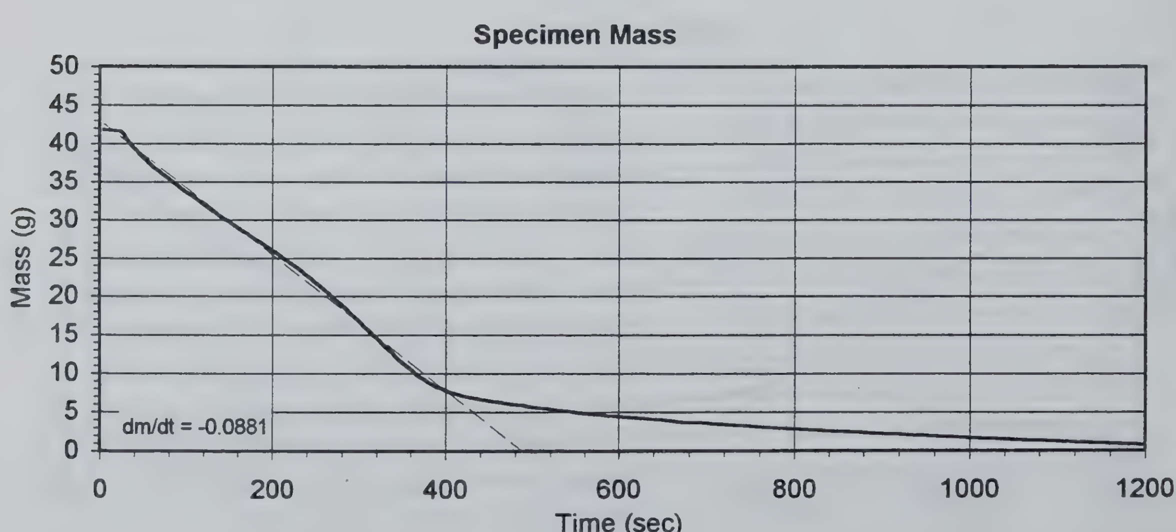




Cone Calorimeter Data R 4.09 Varnished Massive Timber
40 kW/m^2, Test #1







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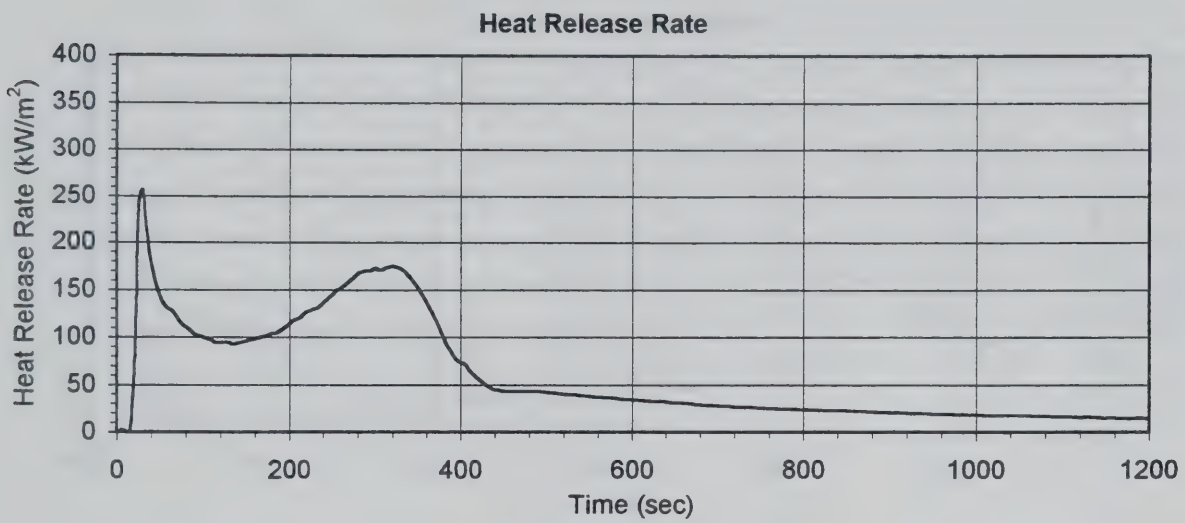
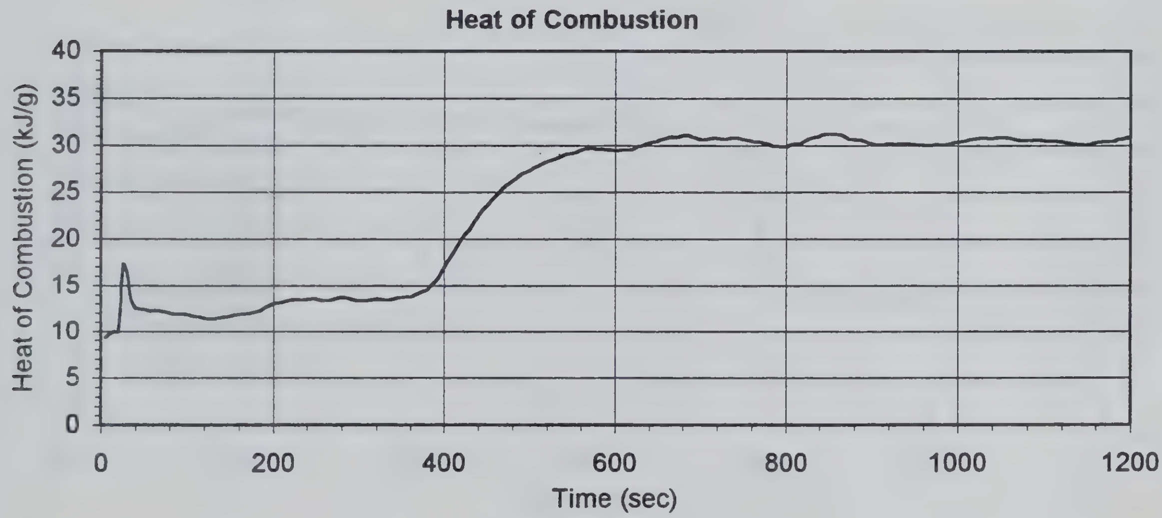
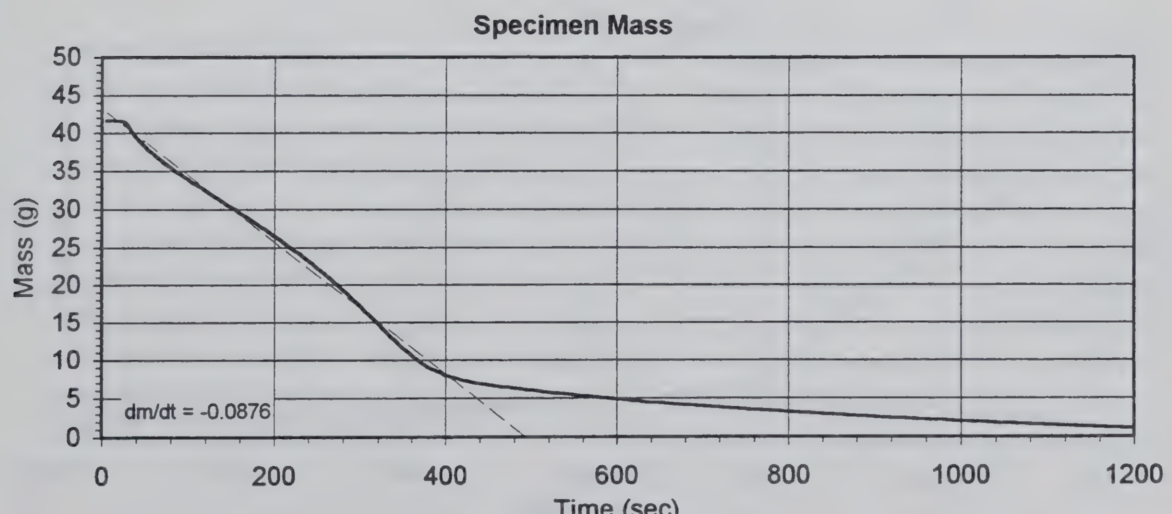
40 kW/m^2, Test #2







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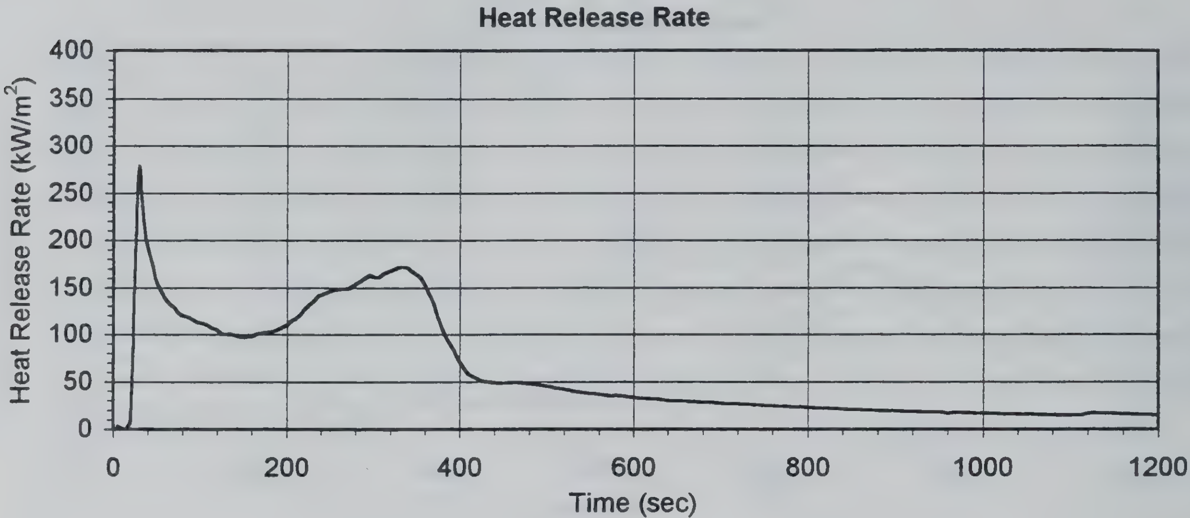
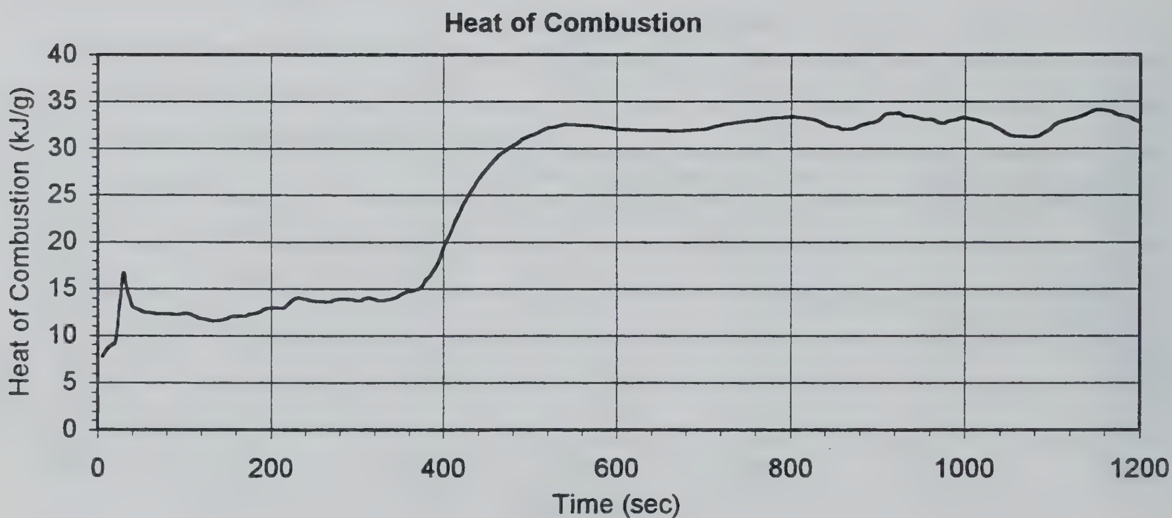
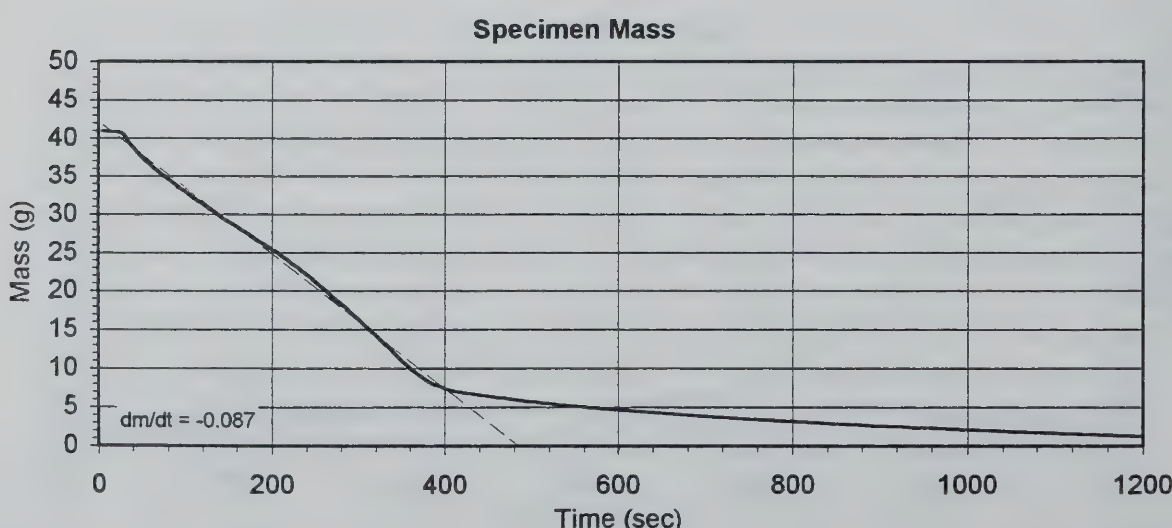
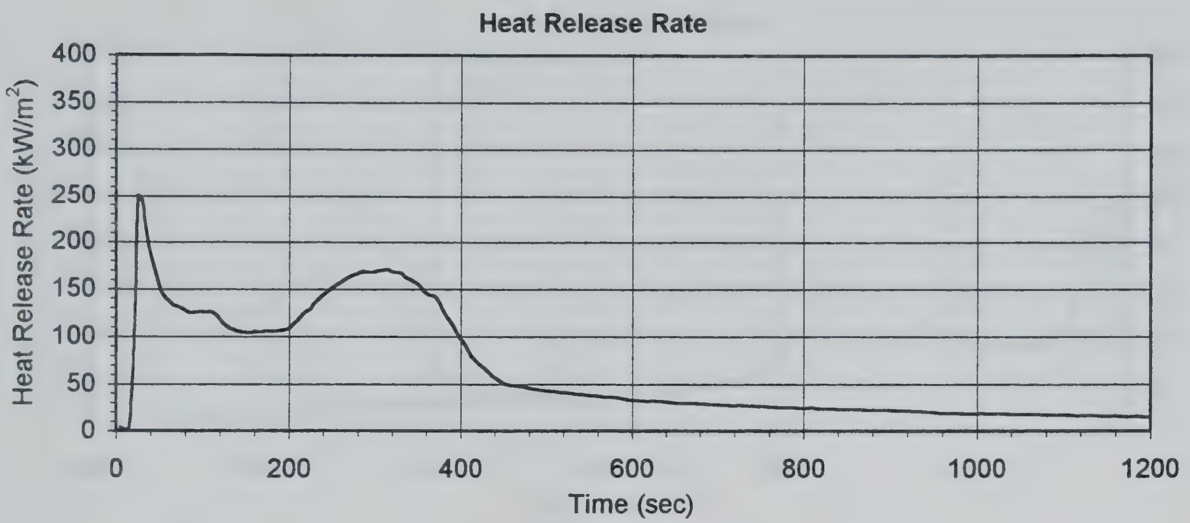


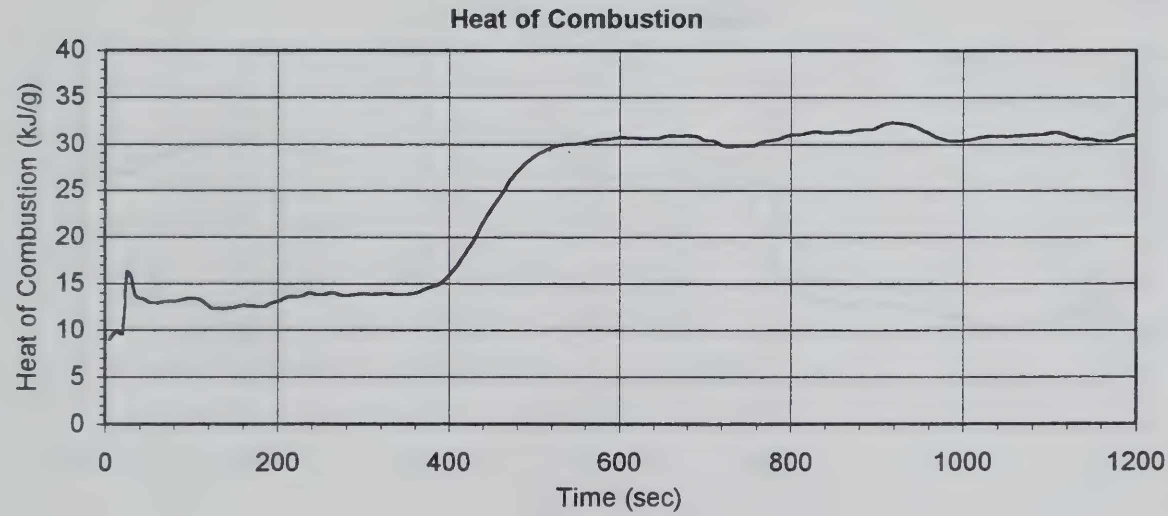


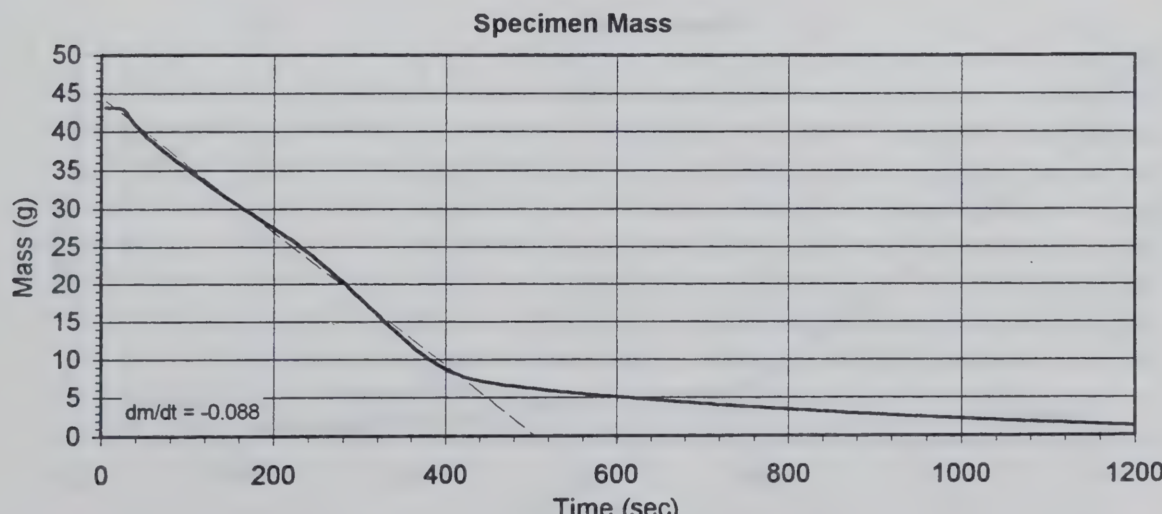


Cone Calorimeter Data R 4.09 Varnished Massive Timber

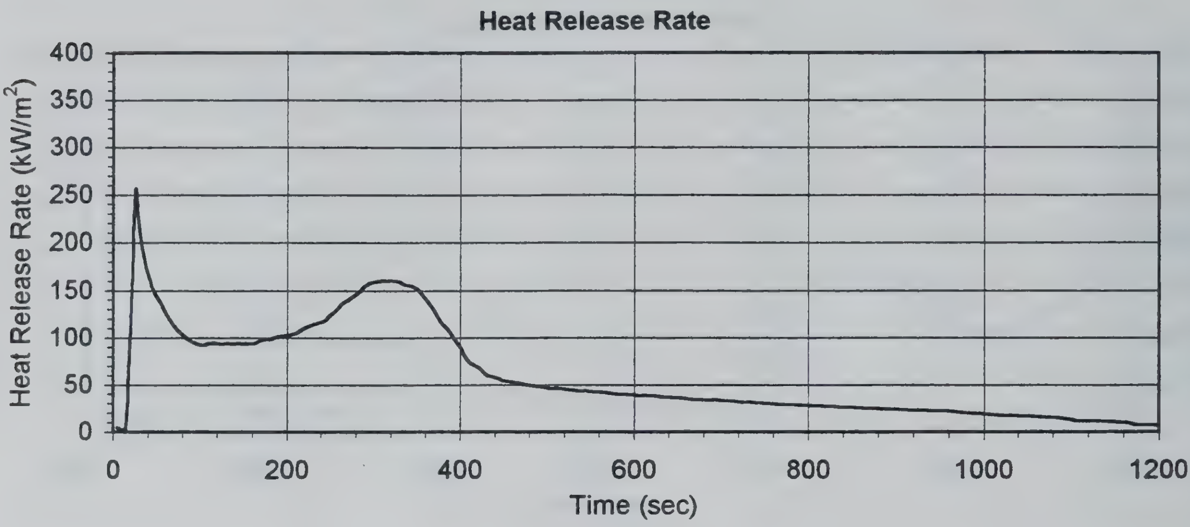
40 kW/m^2, Test #4

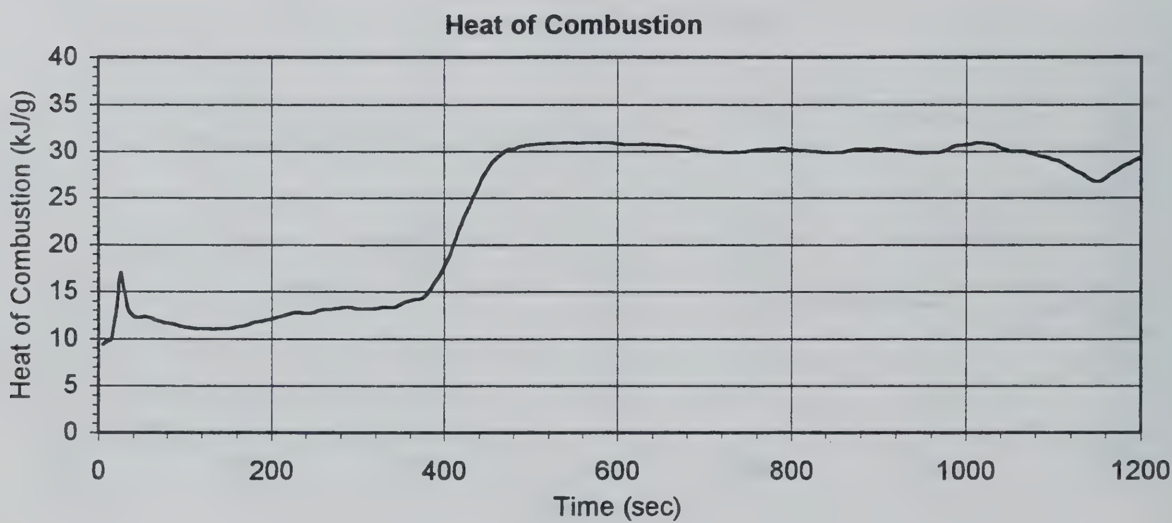


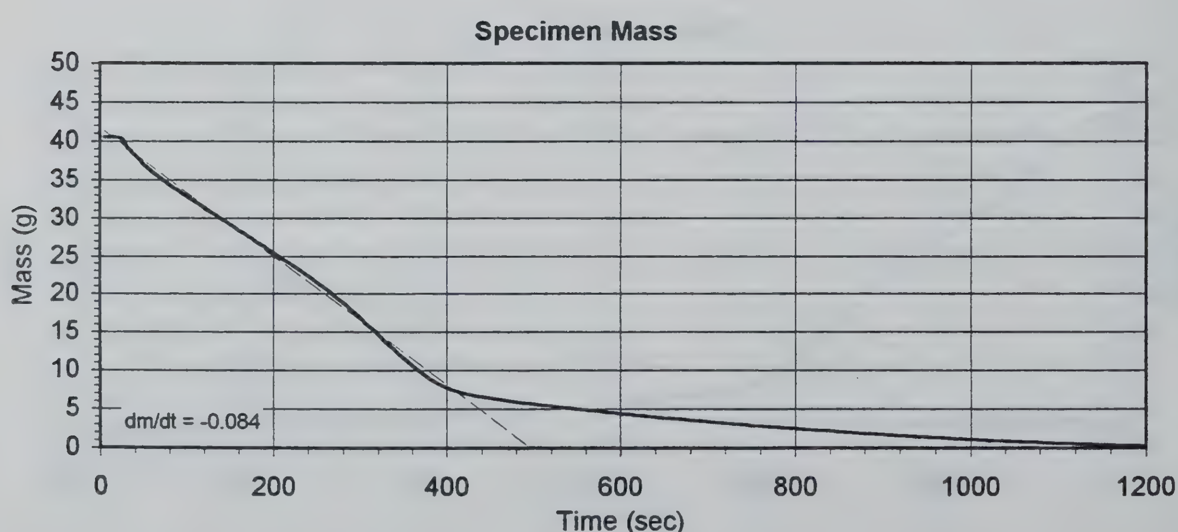




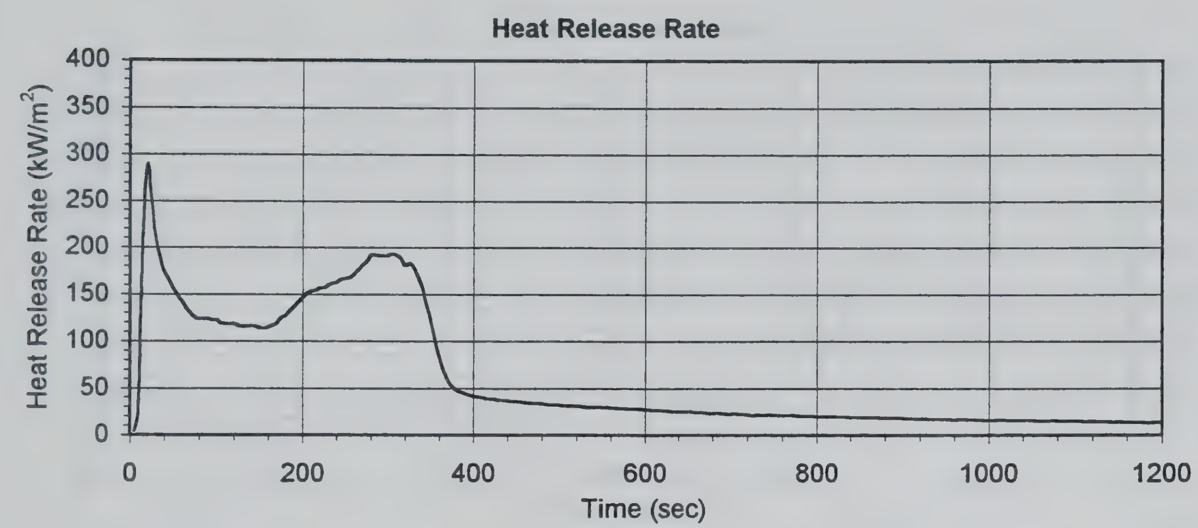
Cone Calorimeter Data R 4.09 Varnished Massive Timber
40 kW/m^2, Test #5

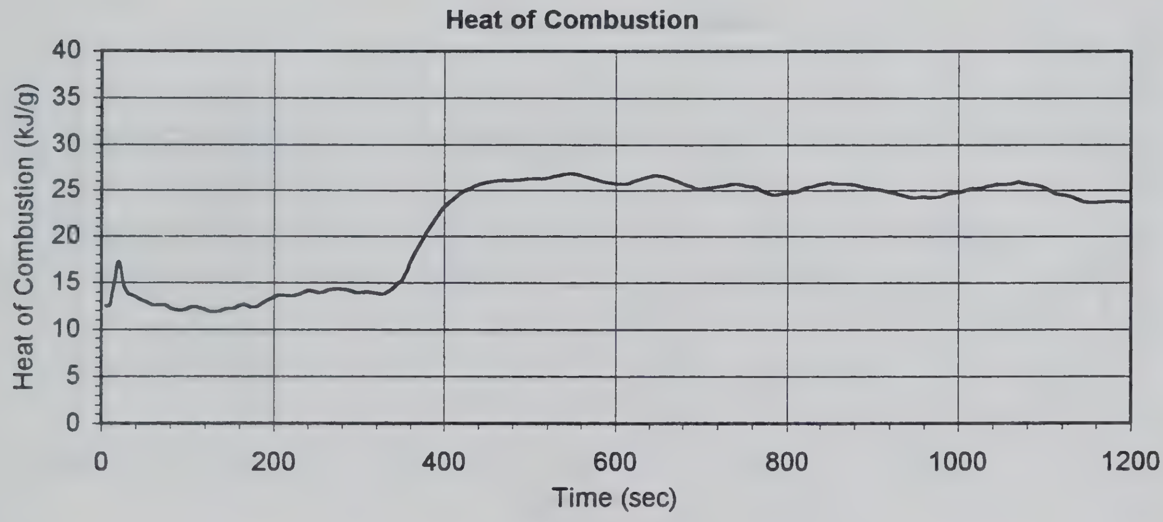


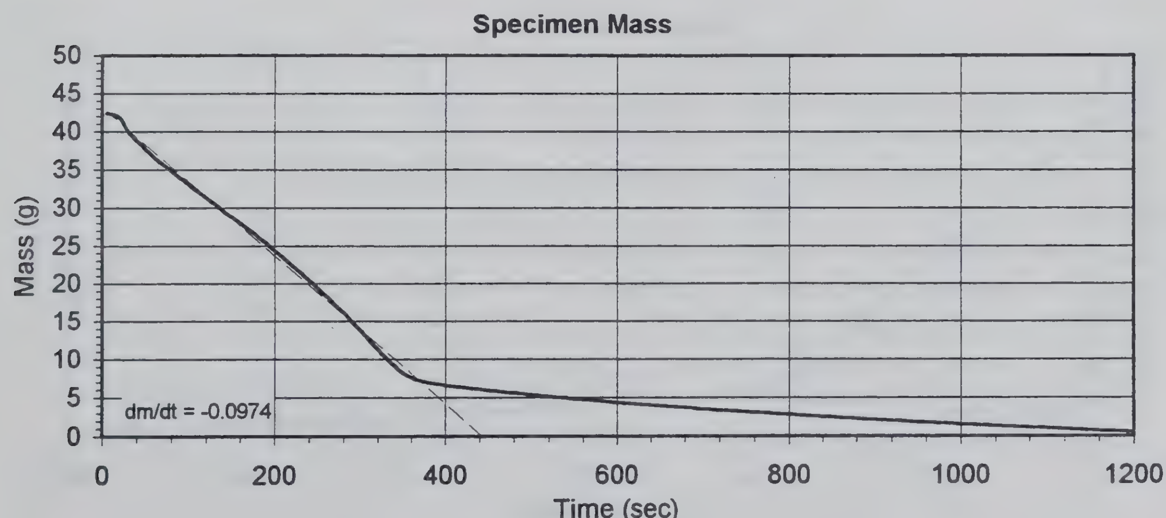




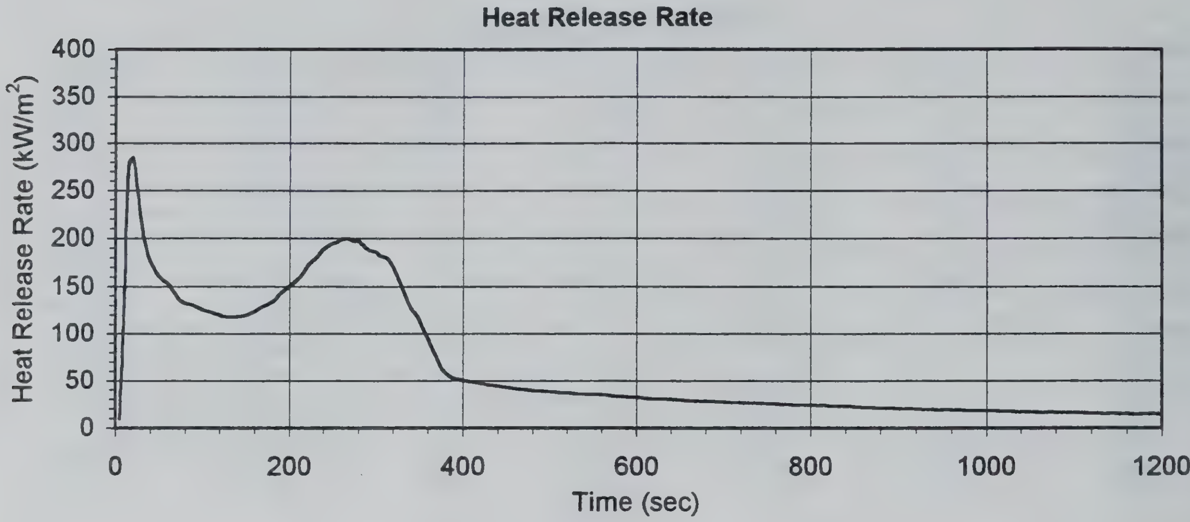
Cone Calorimeter Data R 4.09 Varnished Massive Timber
50 kW/m², Test #1

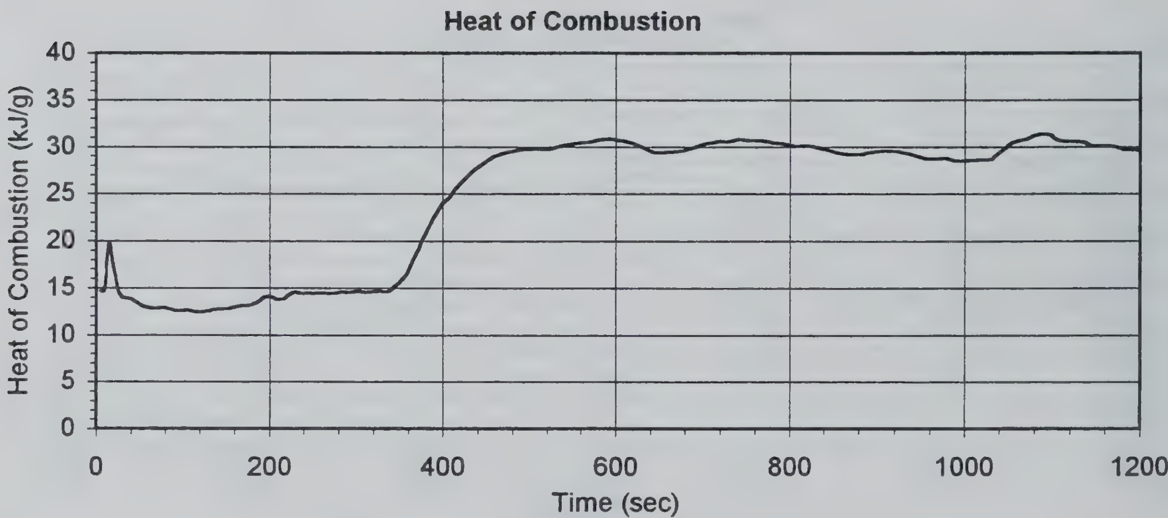


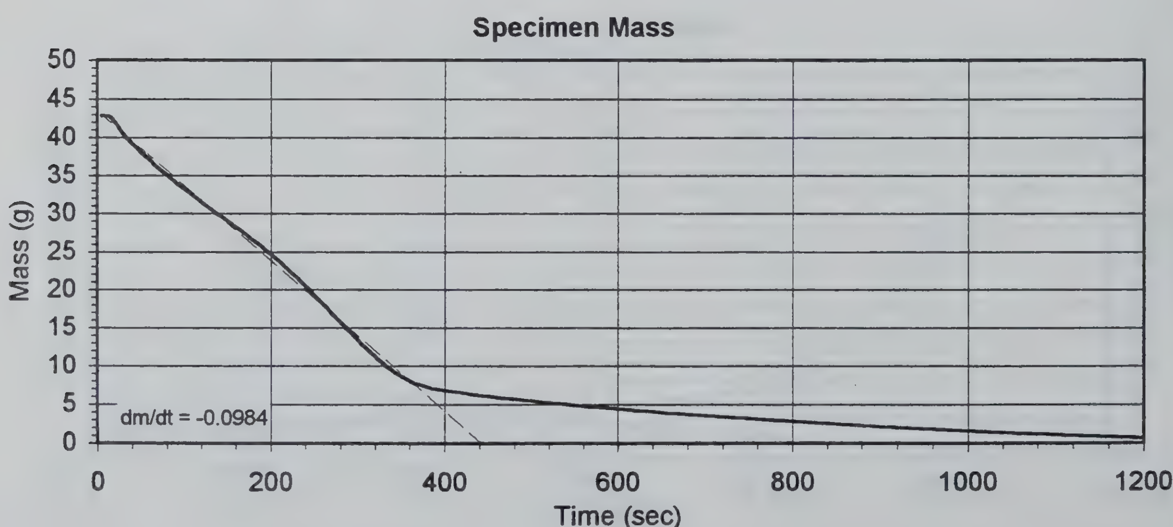




Cone Calorimeter Data R 4.09 Varnished Massive Timber
50 kW/m^2, Test #2

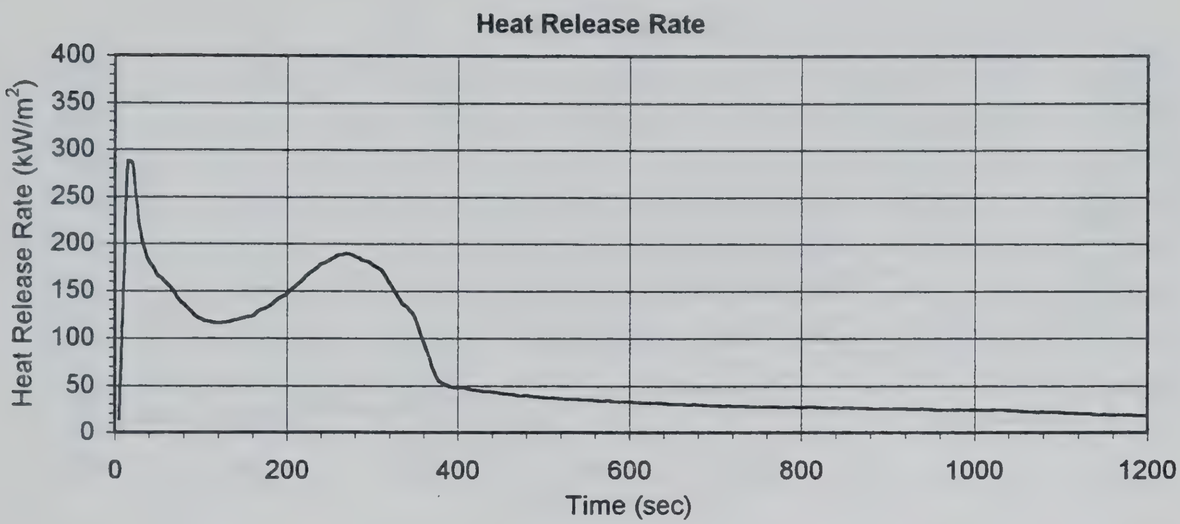


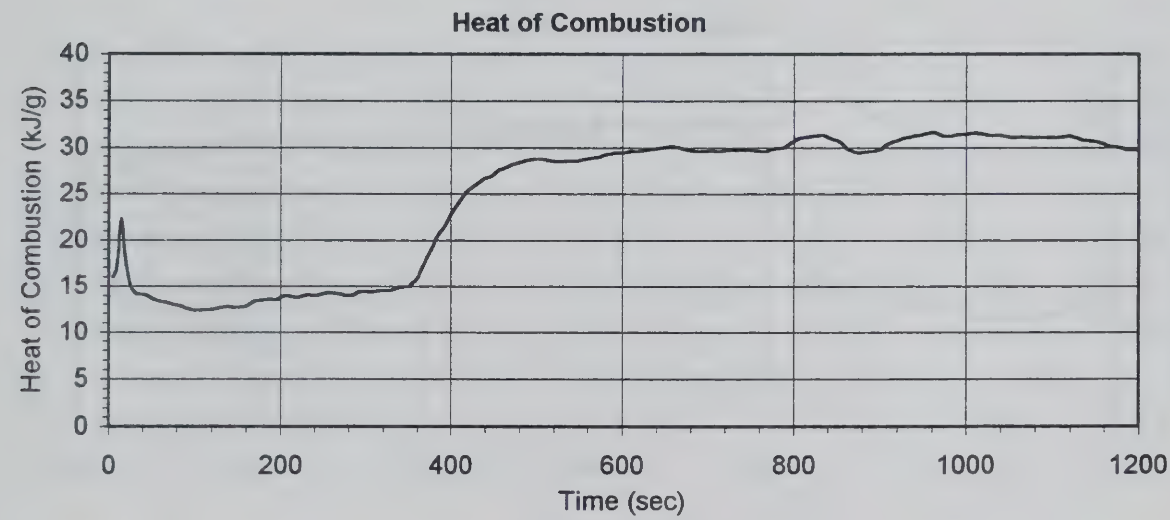


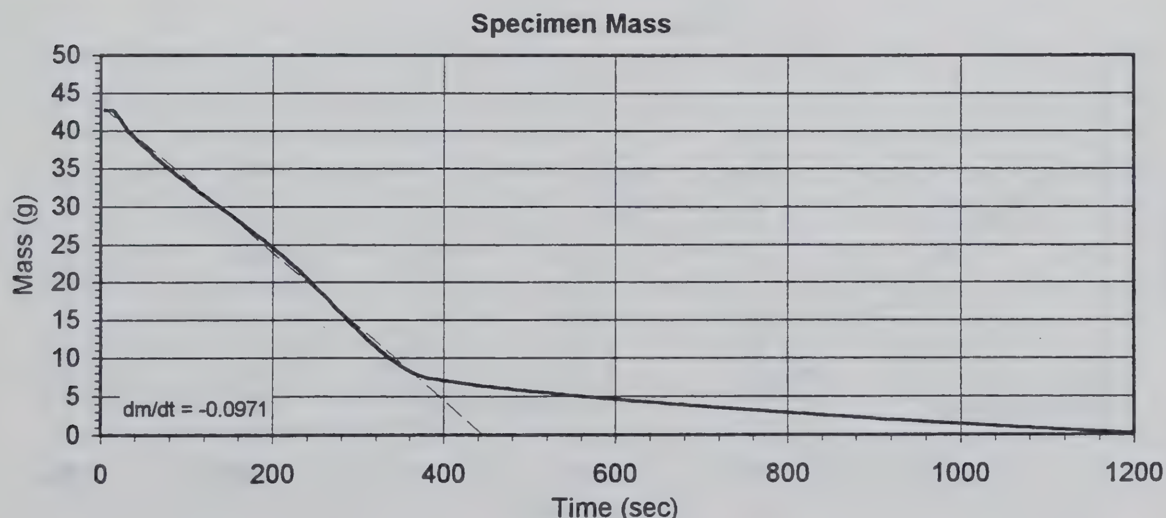


Cone Calorimeter Data R 4.09 Varnished Massive Timber

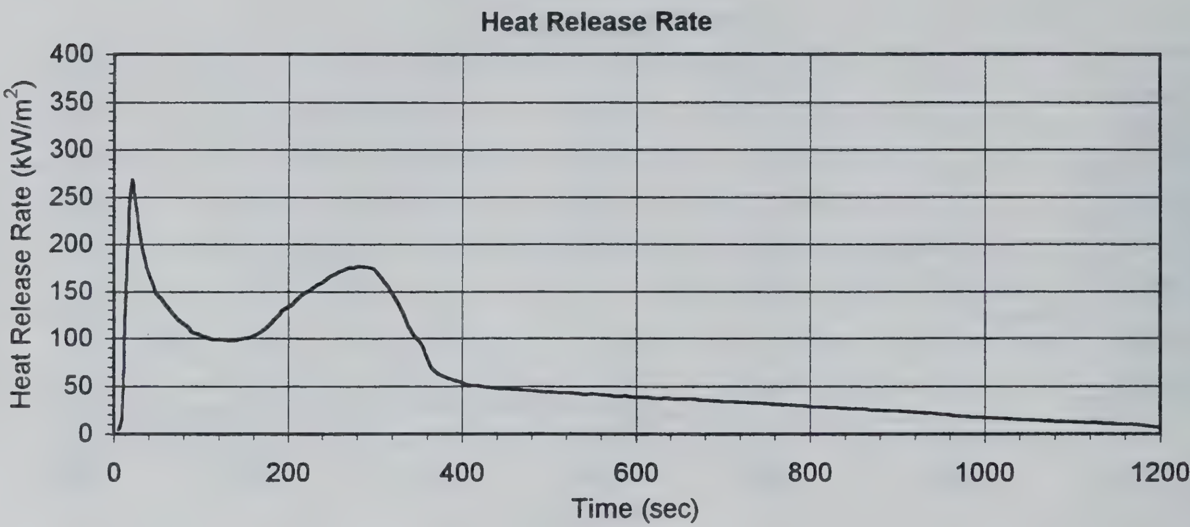
50 kW/m^2, Test #3

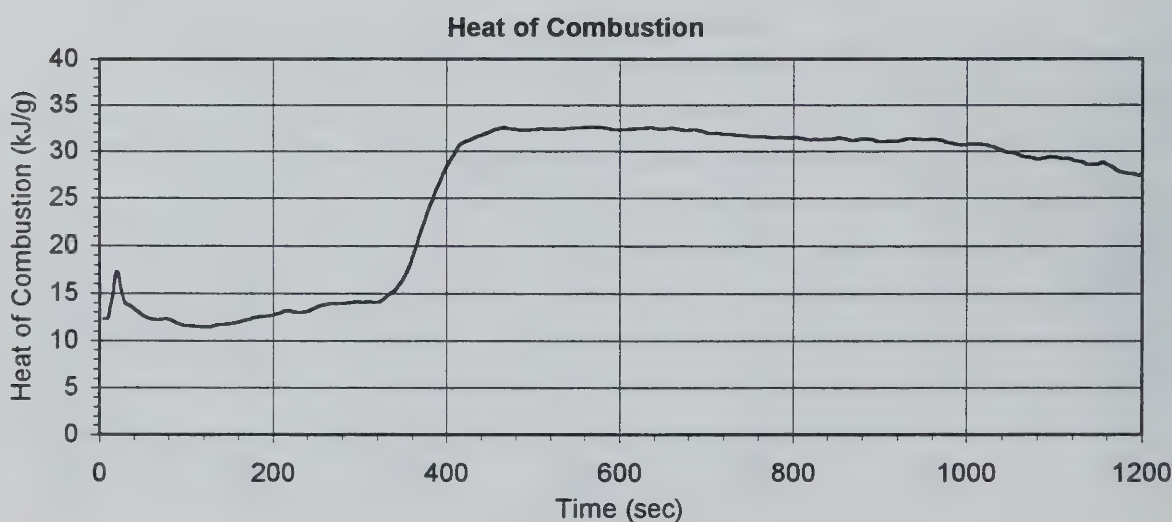


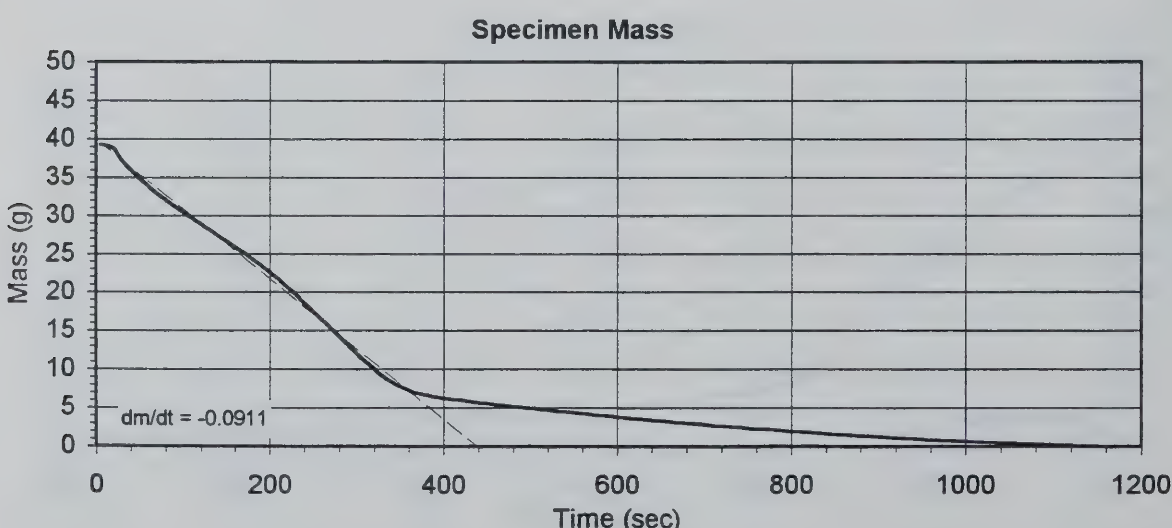




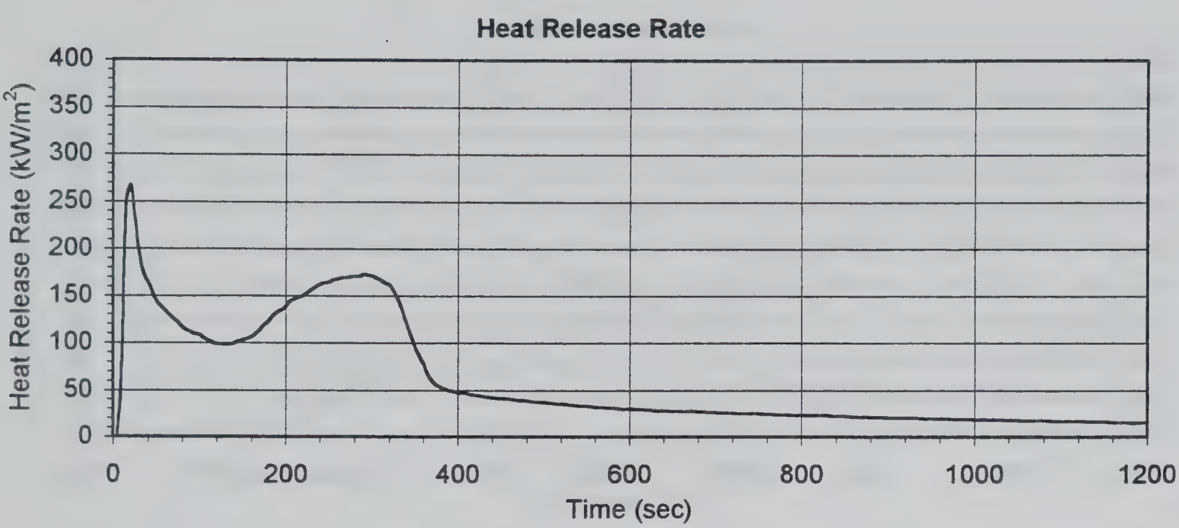
Cone Calorimeter Data R 4.09 Varnished Massive Timber
50 kW/m^2, Test #4

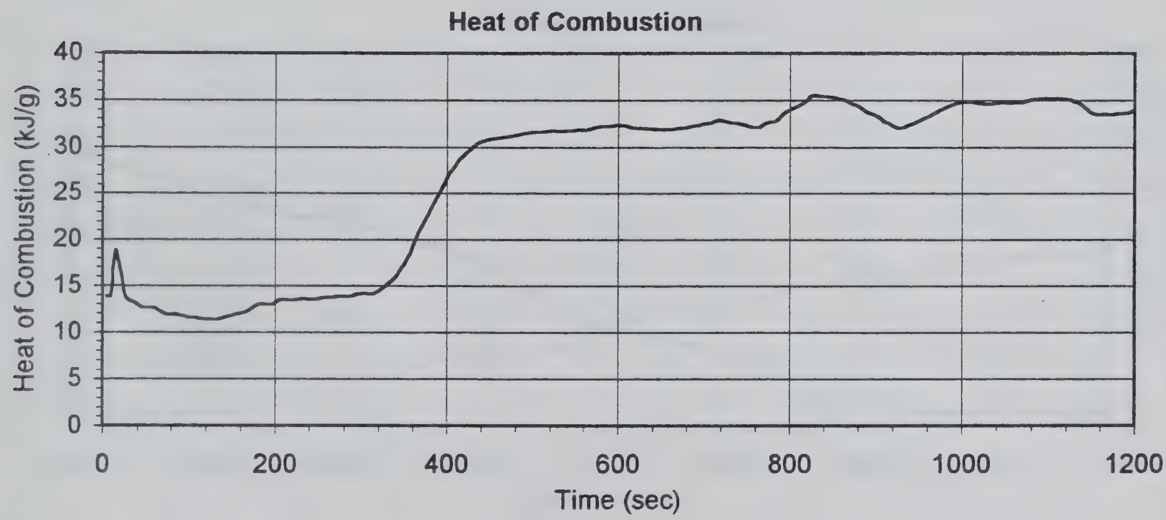


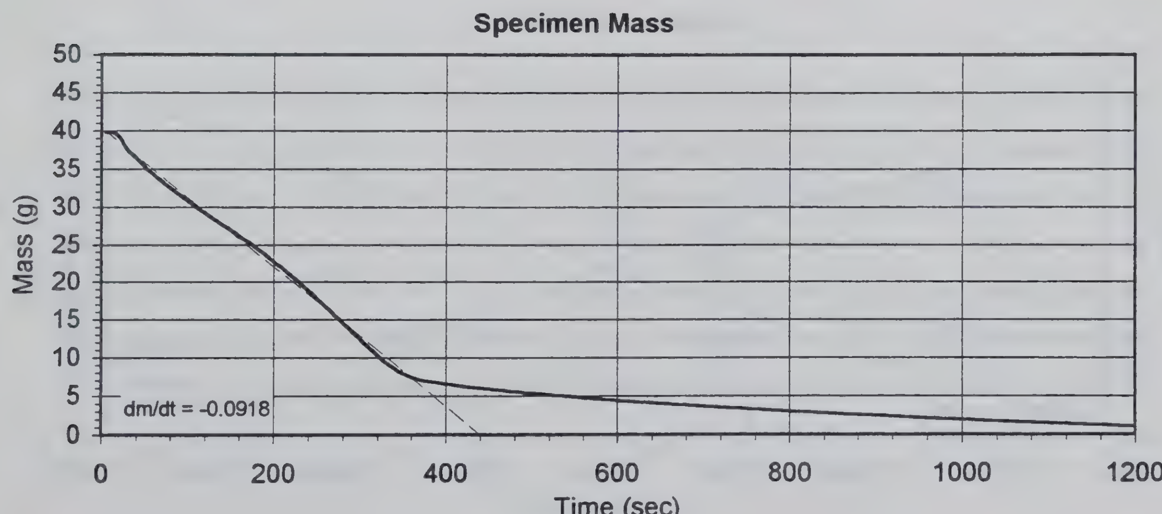




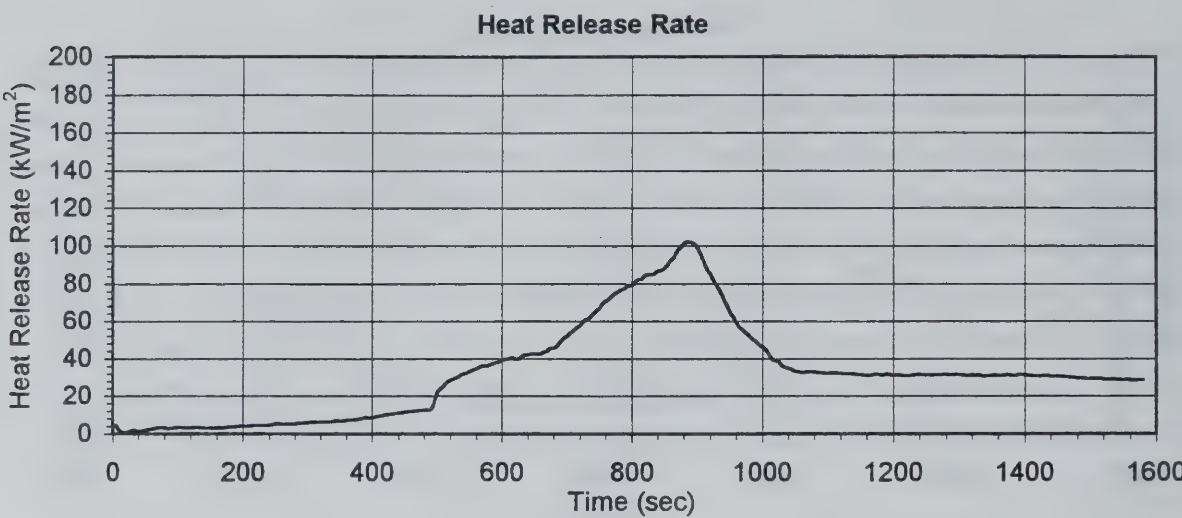
Cone Calorimeter Data R 4.09 Varnished Massive Timber
50 kW/m^2, Test #5

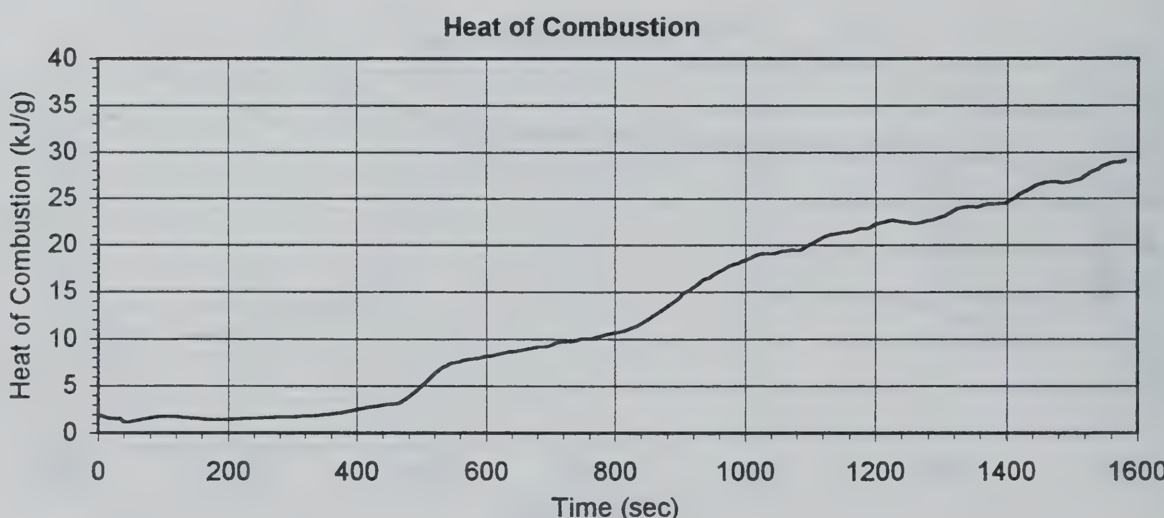


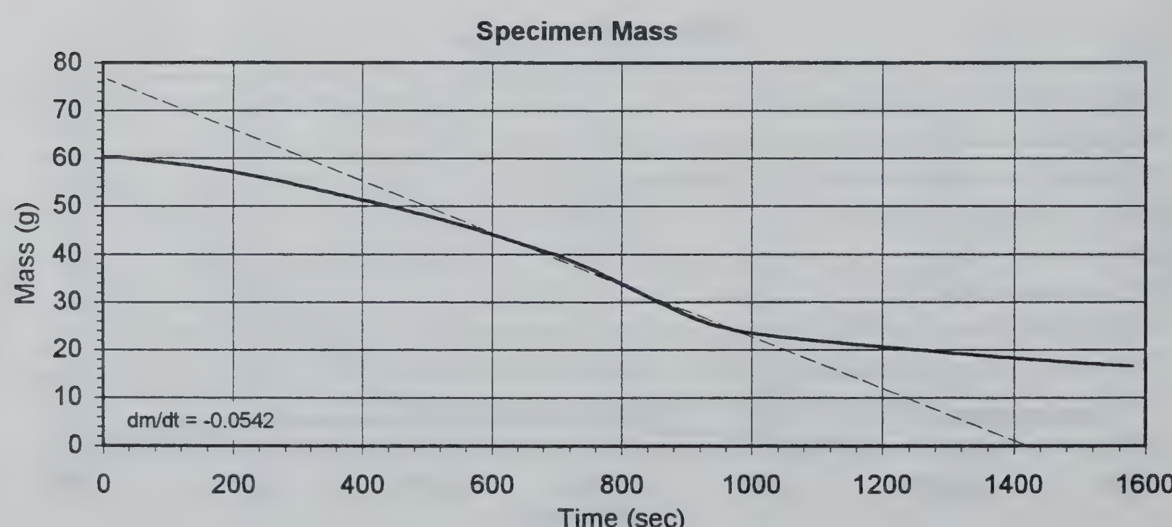




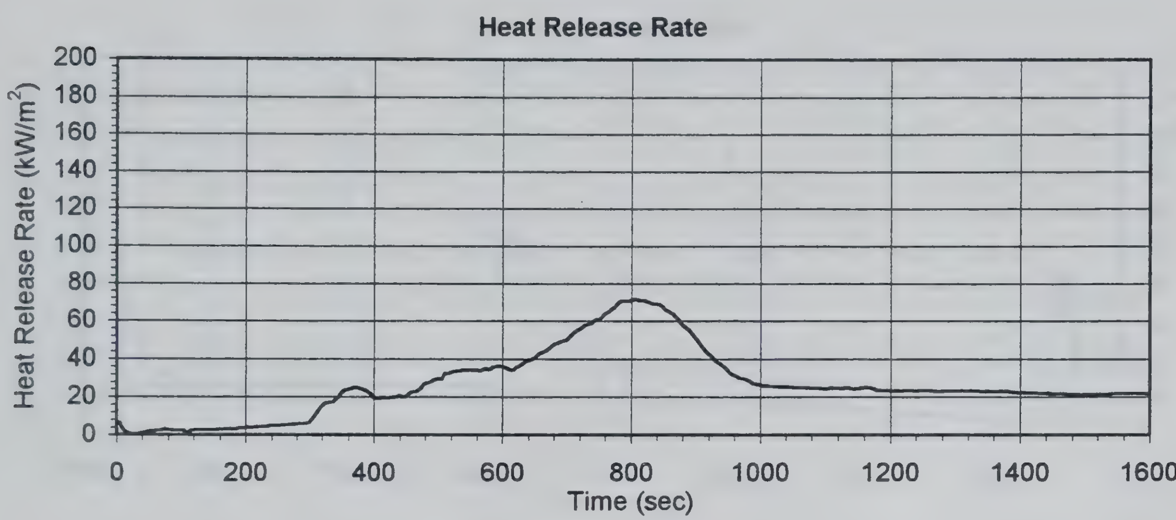
Cone Calorimeter Data R 4.10 F.R. Plywood
25 kW/m^2, Test #1

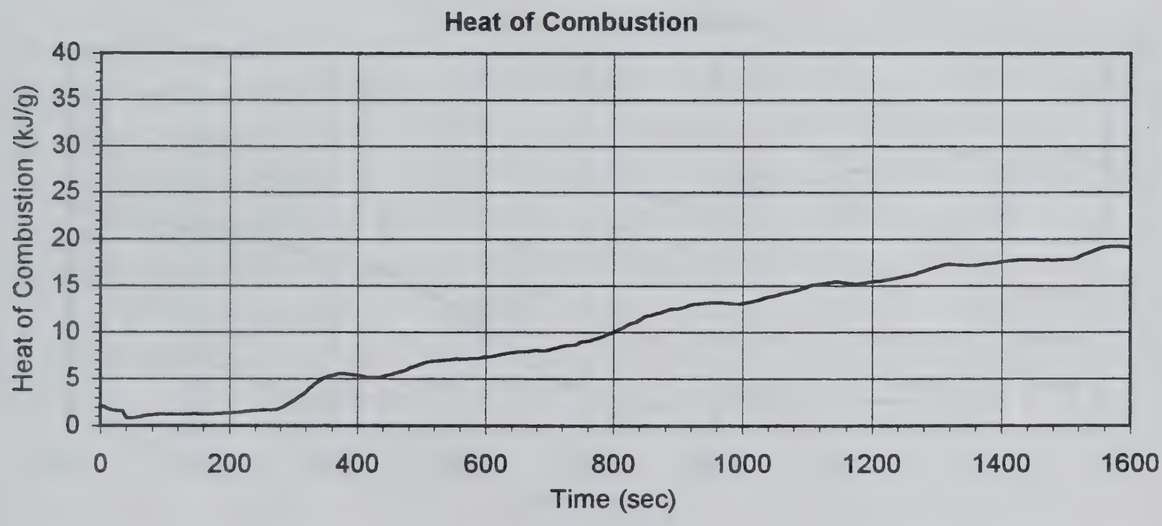


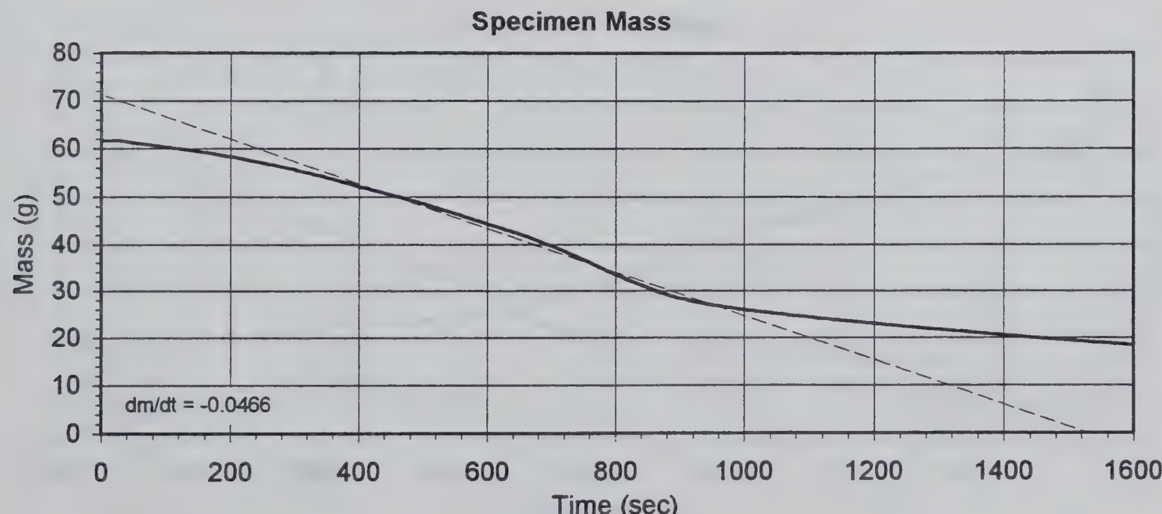




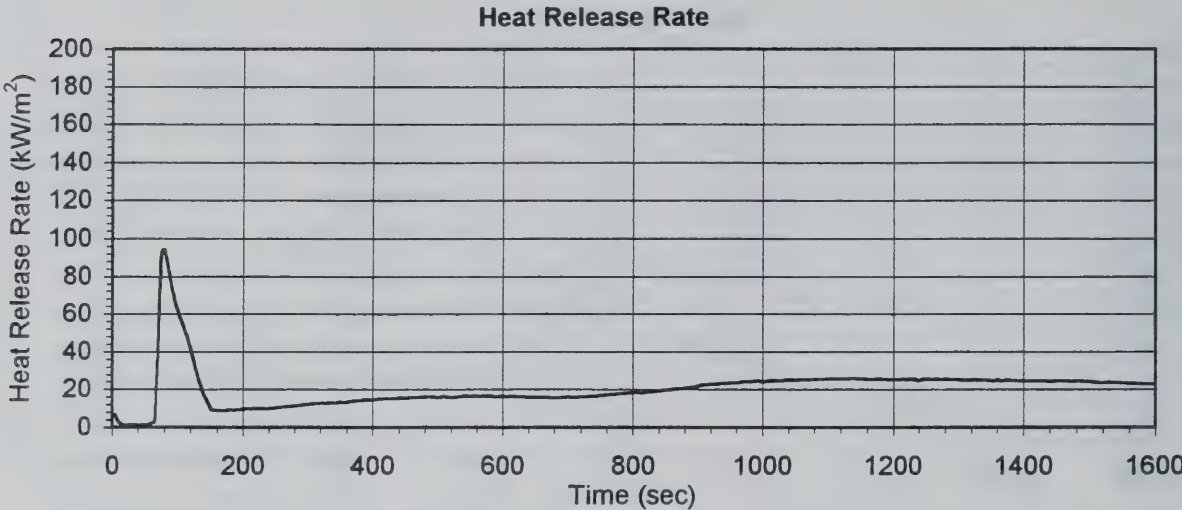
Cone Calorimeter Data R 4.10 F.R. Plywood
25 kW/m^2, Test #4

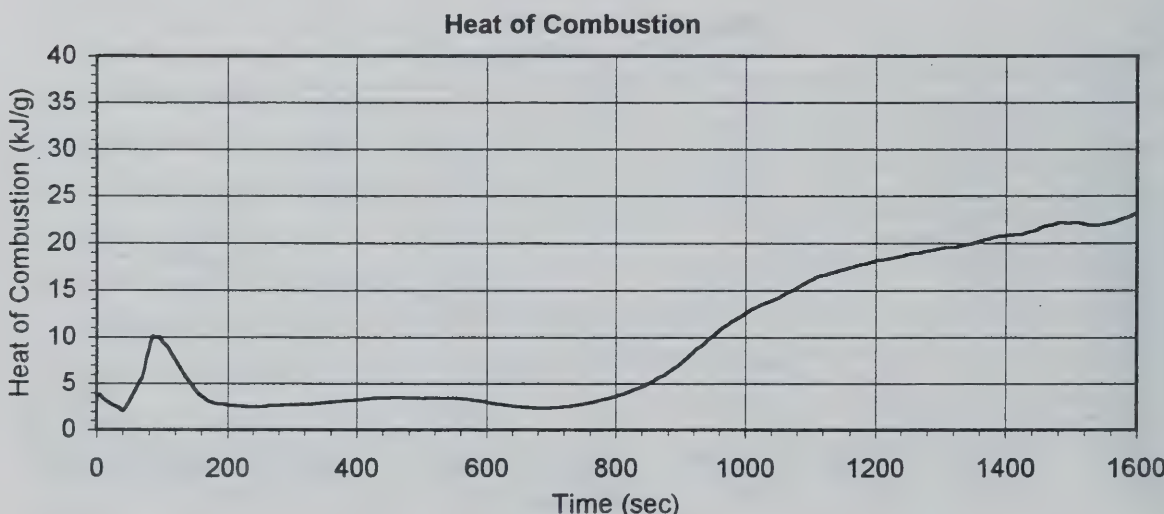


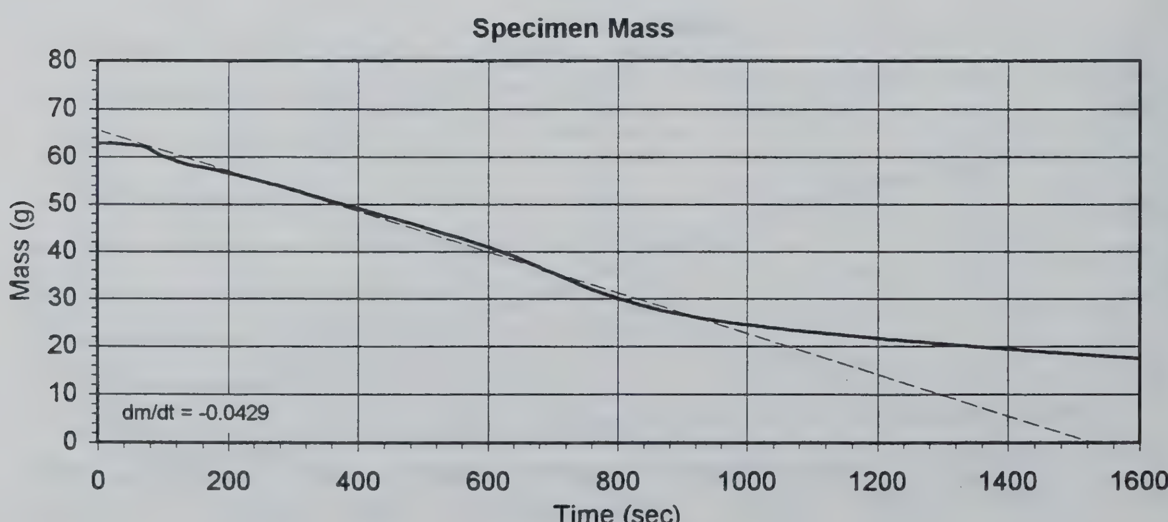




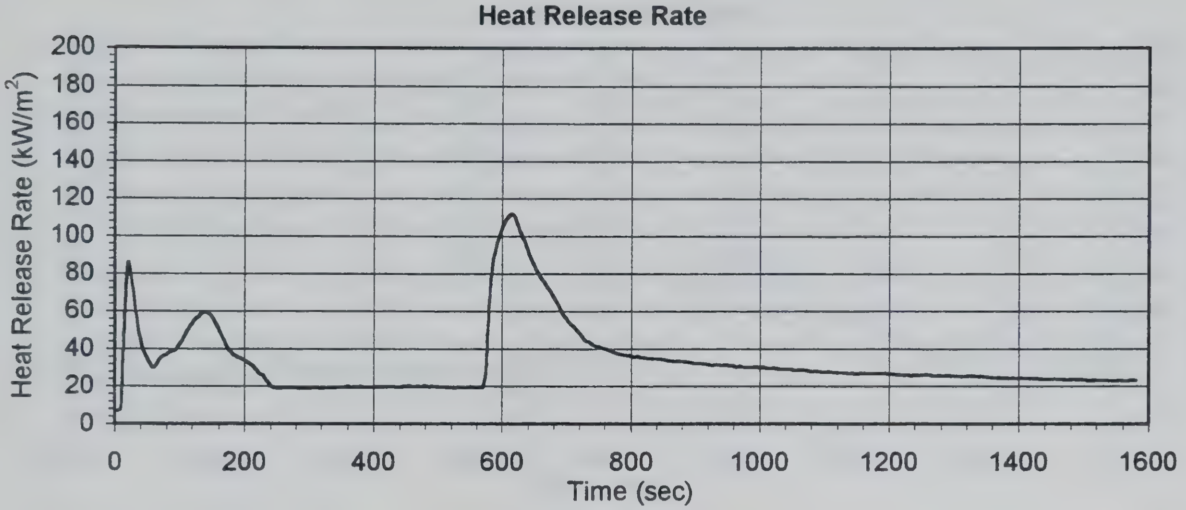
Cone Calorimeter Data R 4.10 F.R. Plywood
25 kW/m², Test #5

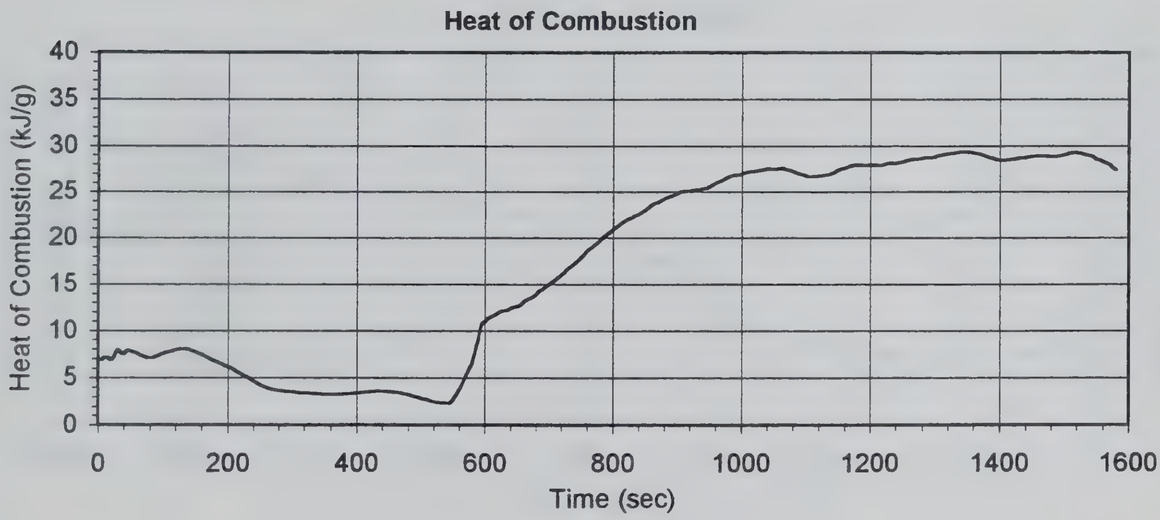


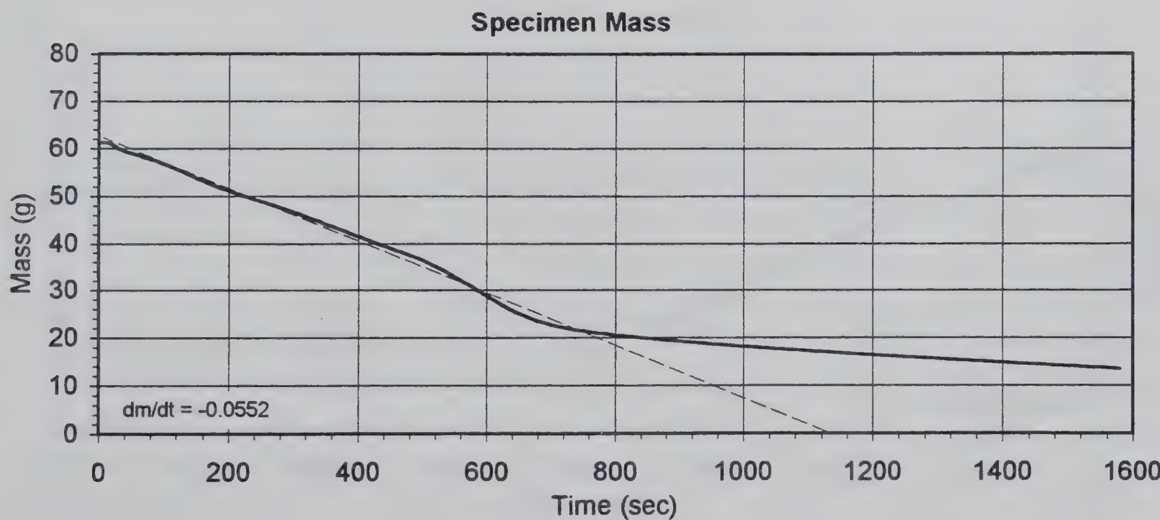




Cone Calorimeter Data R 4.10 F.R. Plywood
35 kW/m^2, Test #1

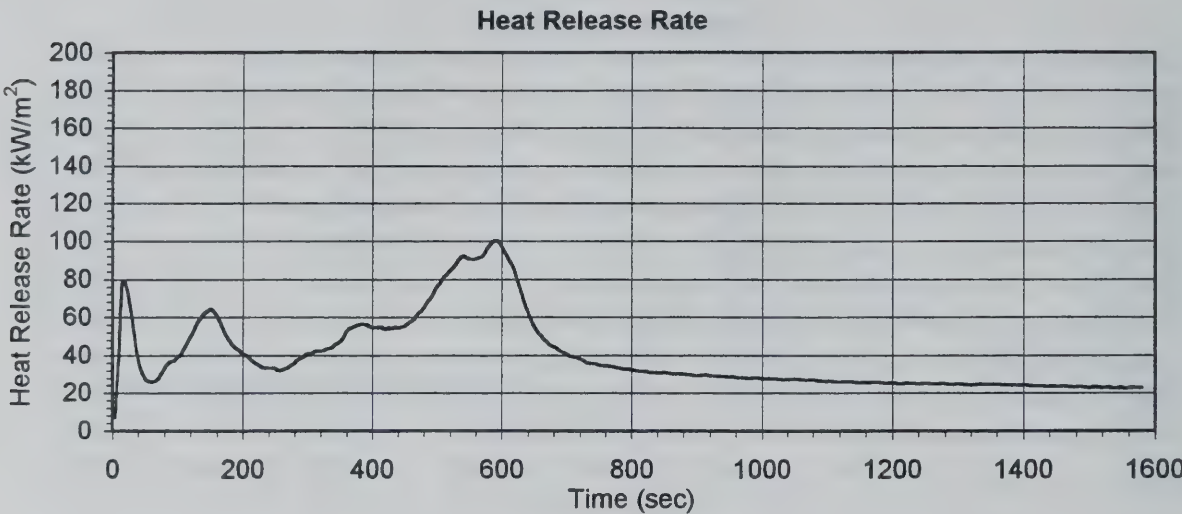


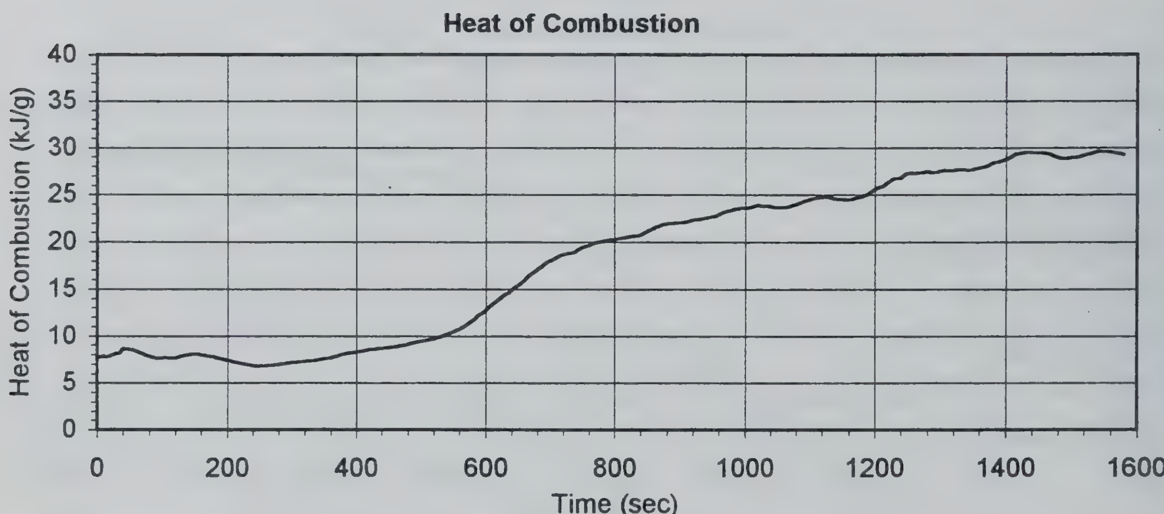


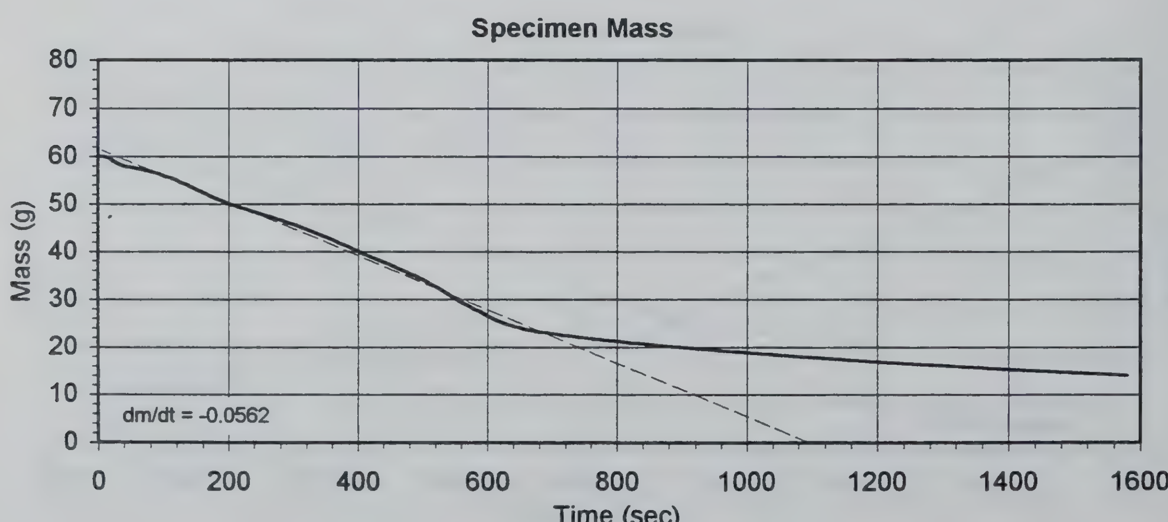


Cone Calorimeter Data R 4.10 F.R. Plywood

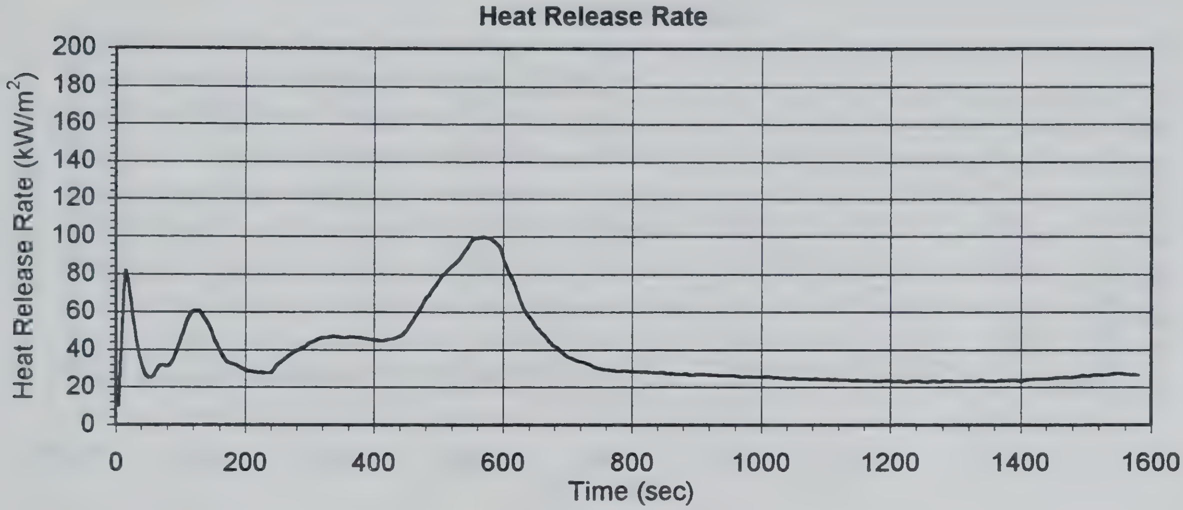
35 kW/m^2, Test #2

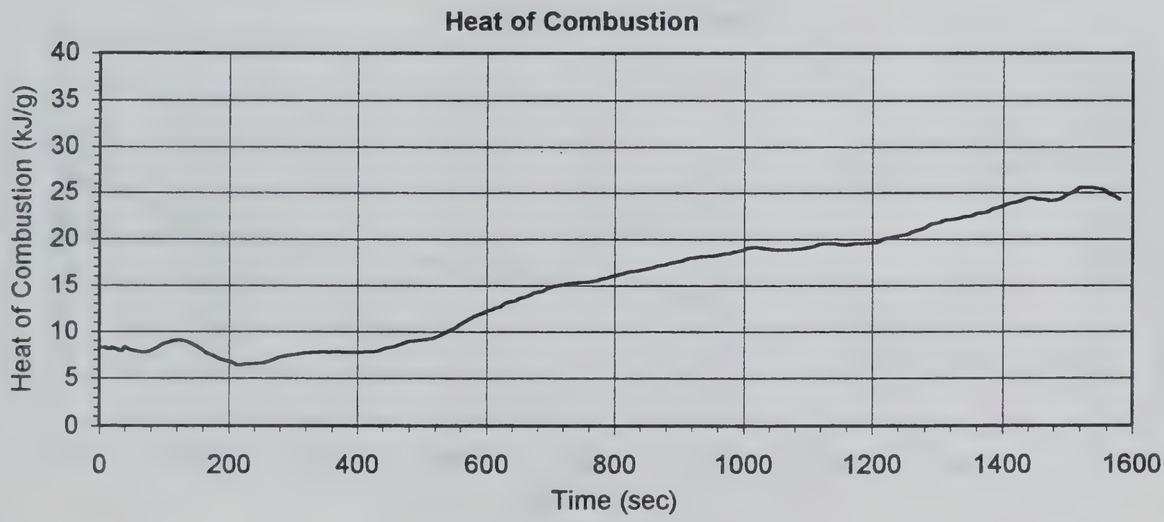


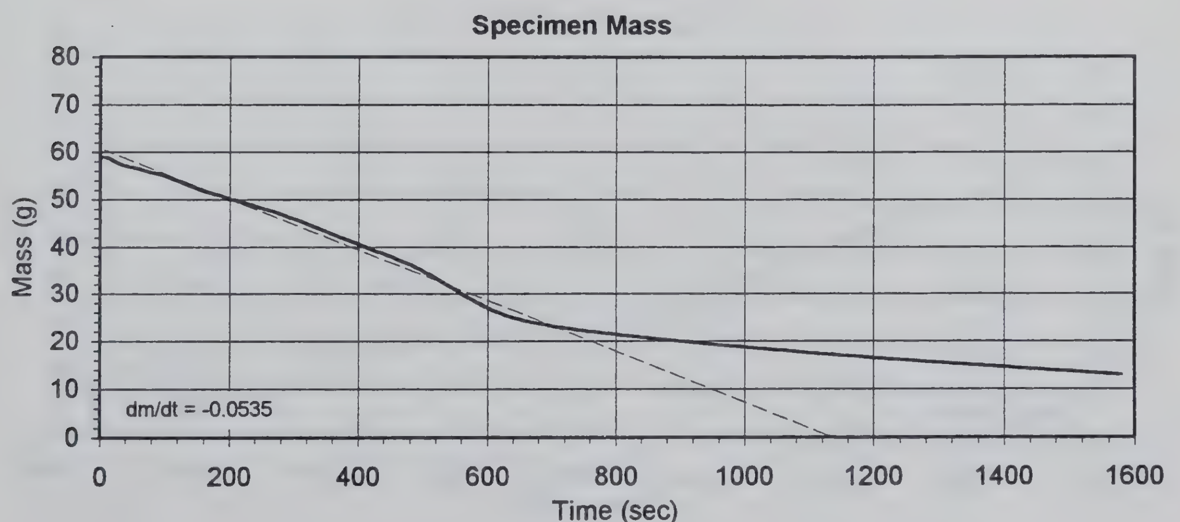




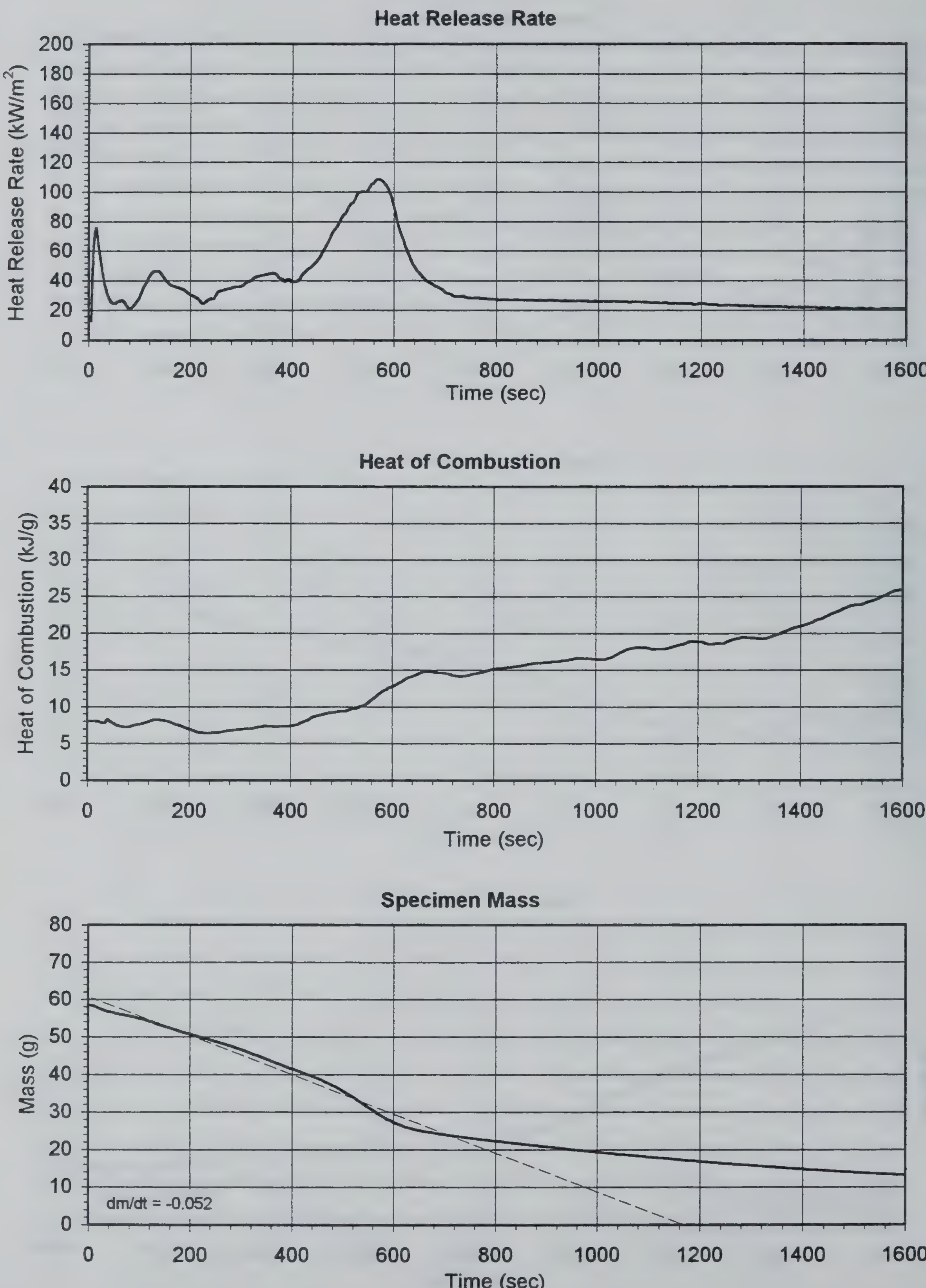
Cone Calorimeter Data R 4.10 F.R. Plywood
35 kW/m², Test #3





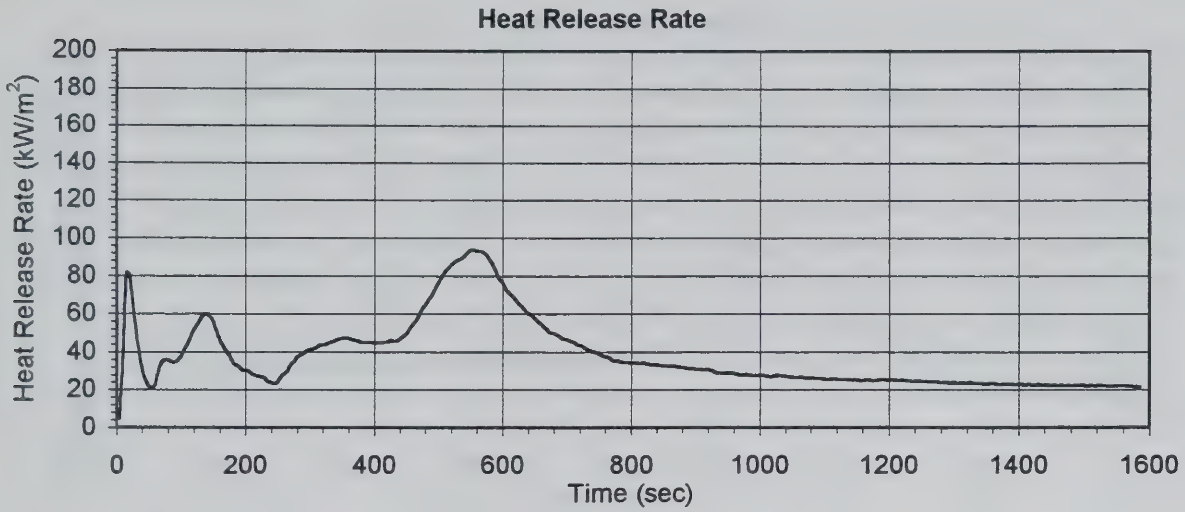


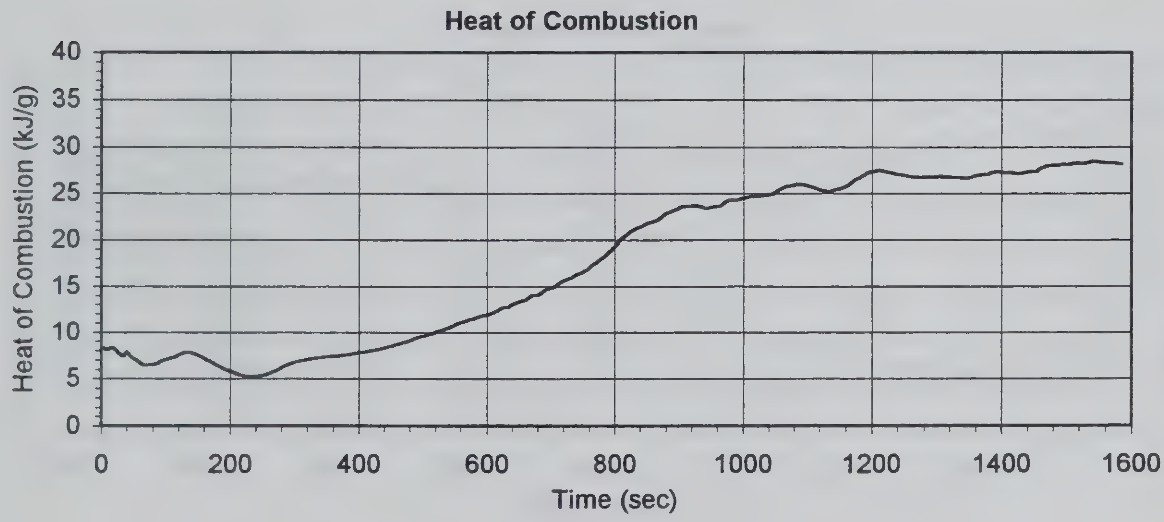
Cone Calorimeter Data R 4.10 F.R. Plywood
35 kW/m^2, Test #4

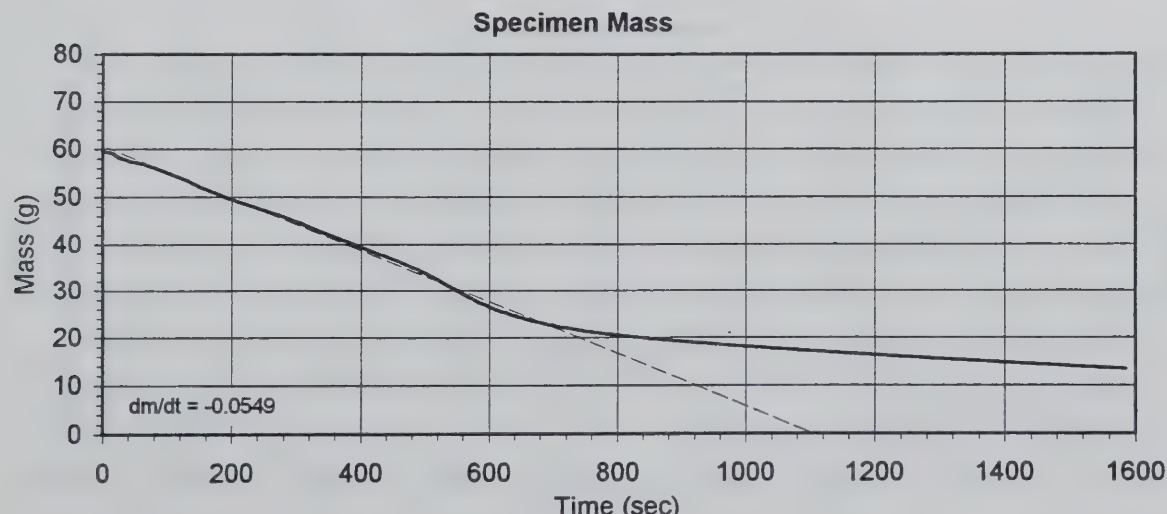


Cone Calorimeter Data R 4.10 F.R. Plywood

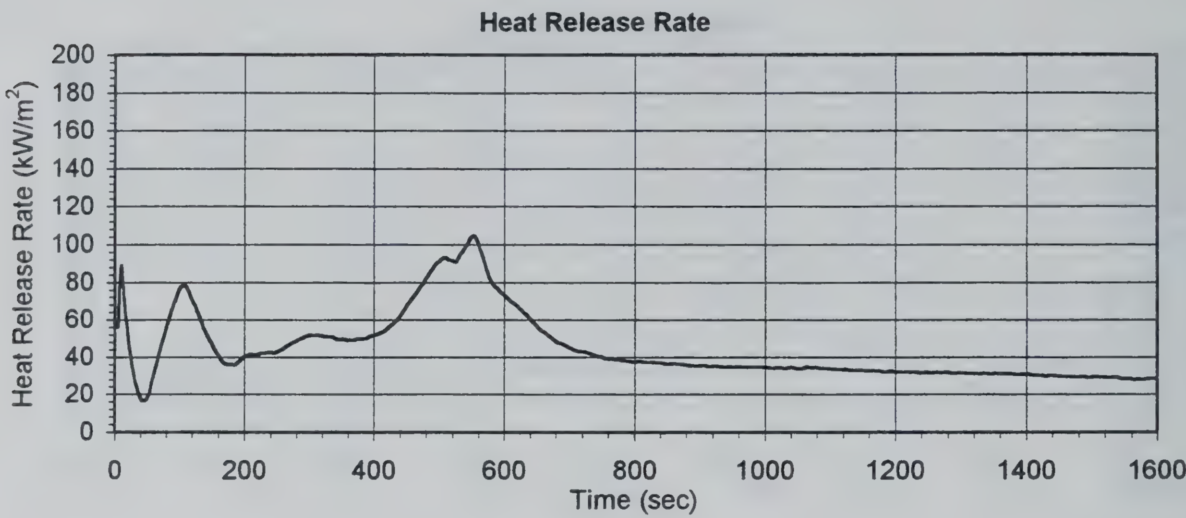
35 kW/m², Test #5

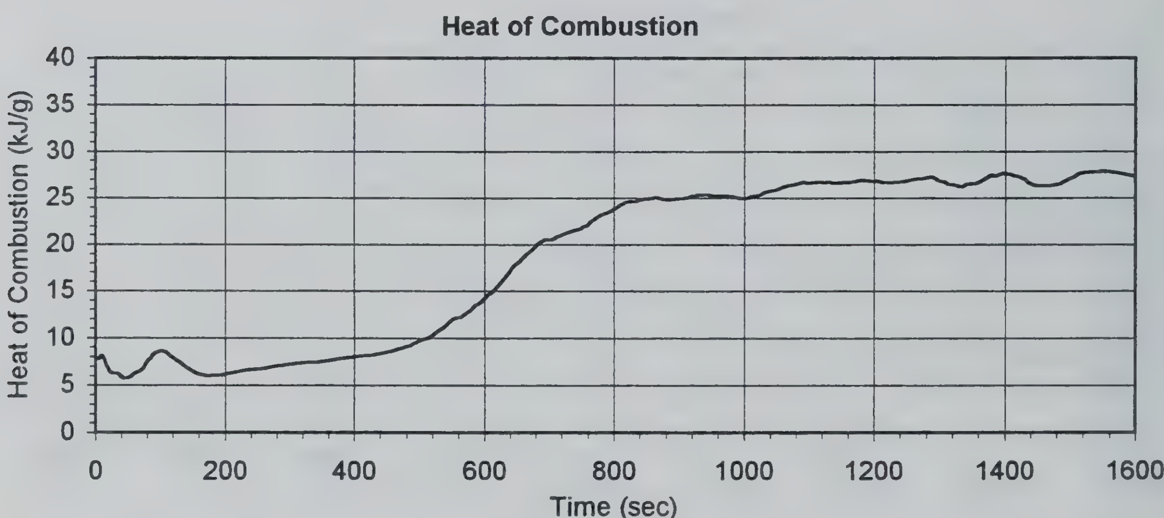


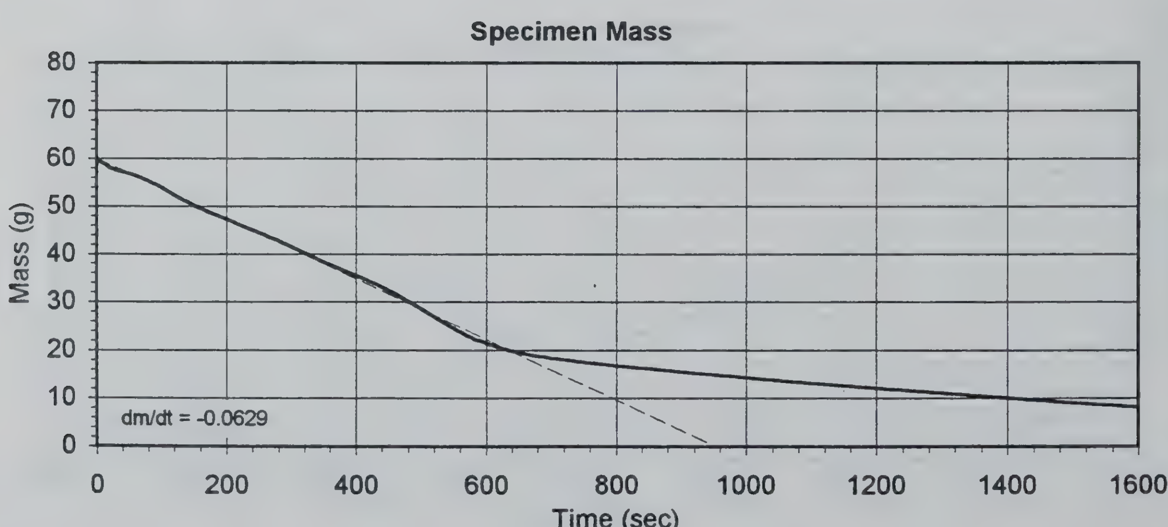




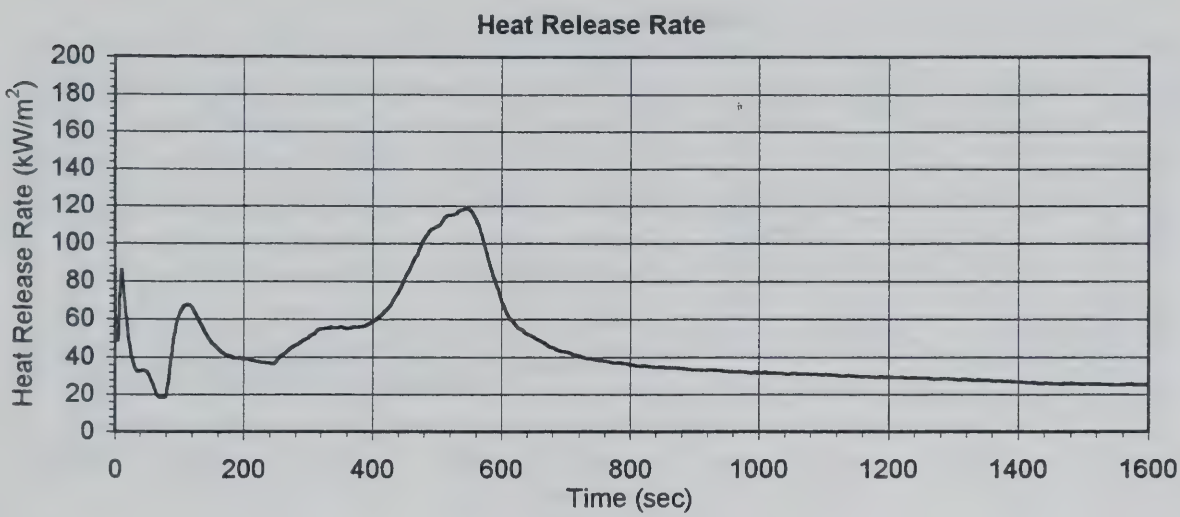
Cone Calorimeter Data R 4.10 F.R. Plywood
40 kW/m^2, Test #1

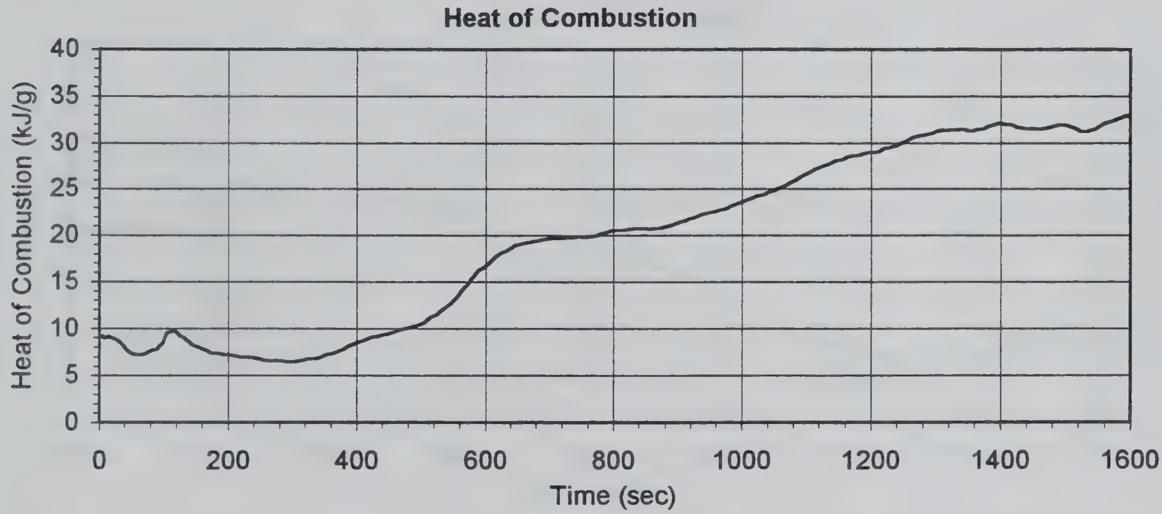


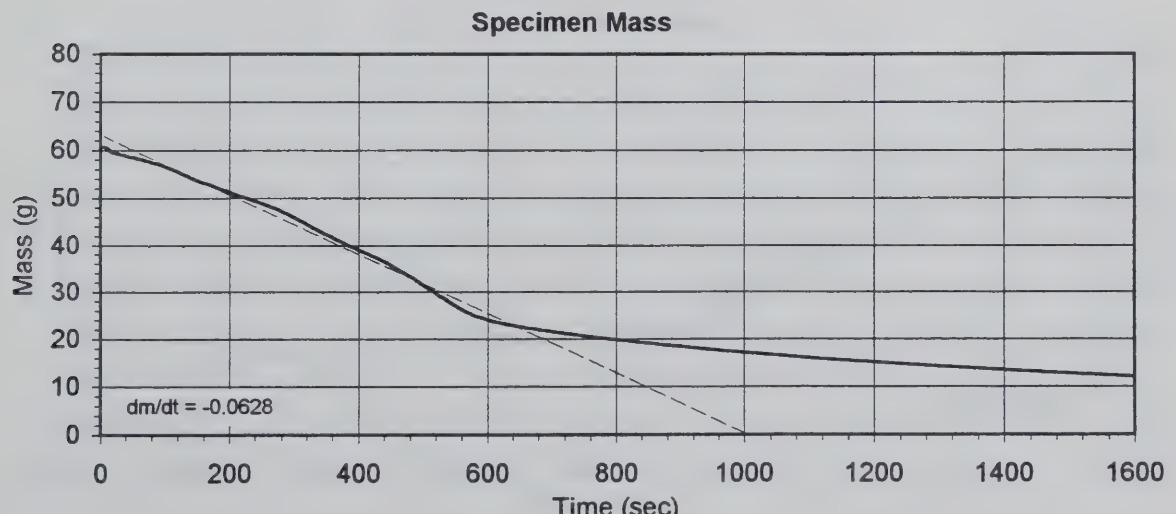




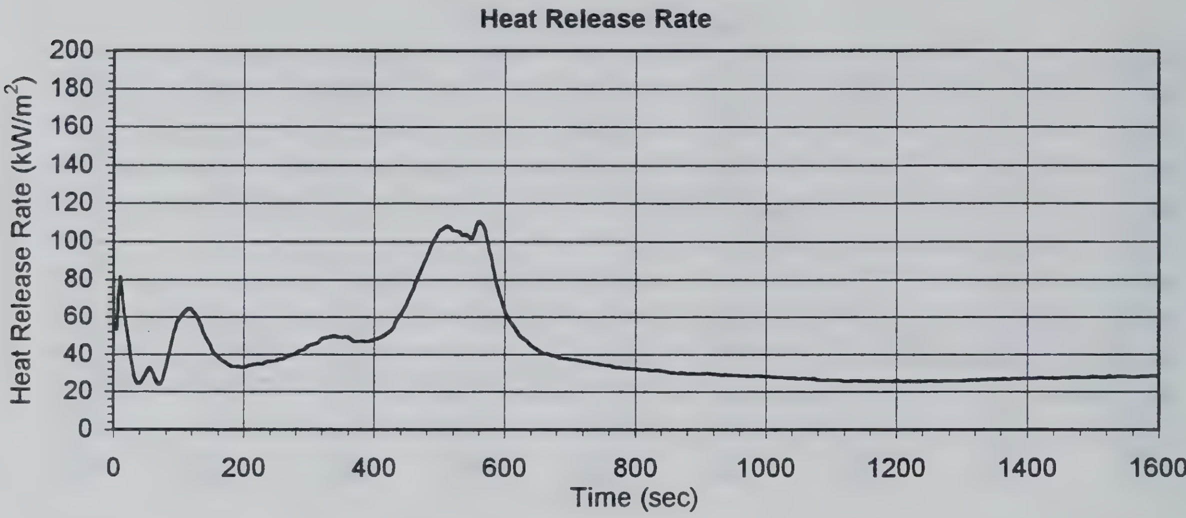
Cone Calorimeter Data R 4.10 F.R. Plywood
40 kW/m^2, Test #2

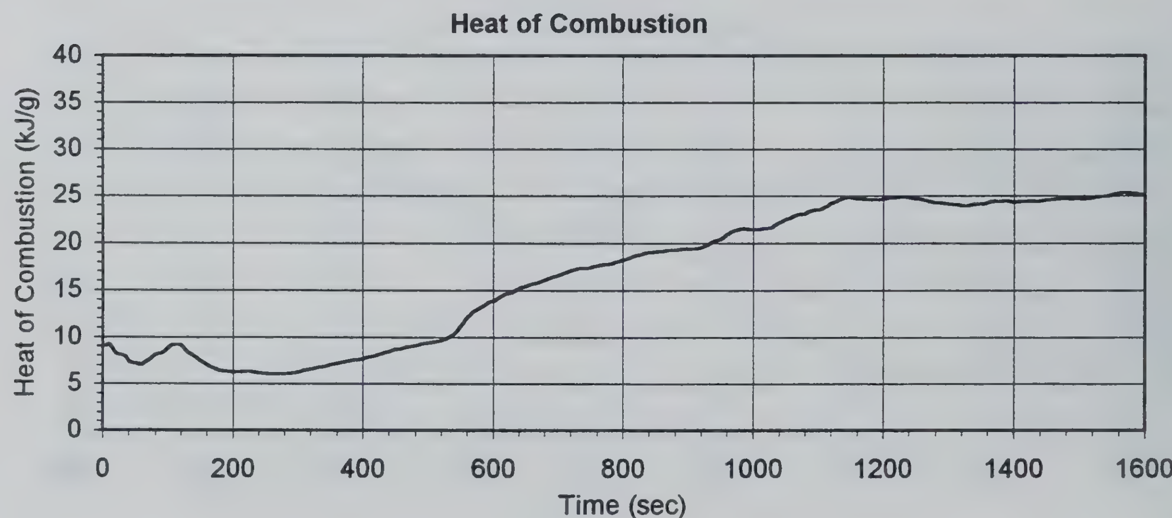


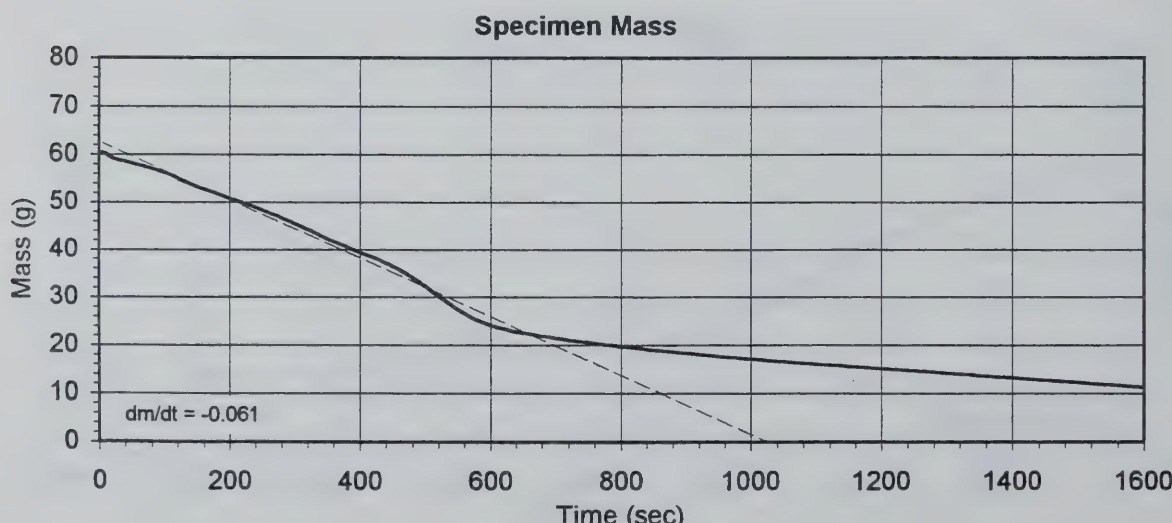




Cone Calorimeter Data R 4.10 F.R. Plywood
40 kW/m², Test #3

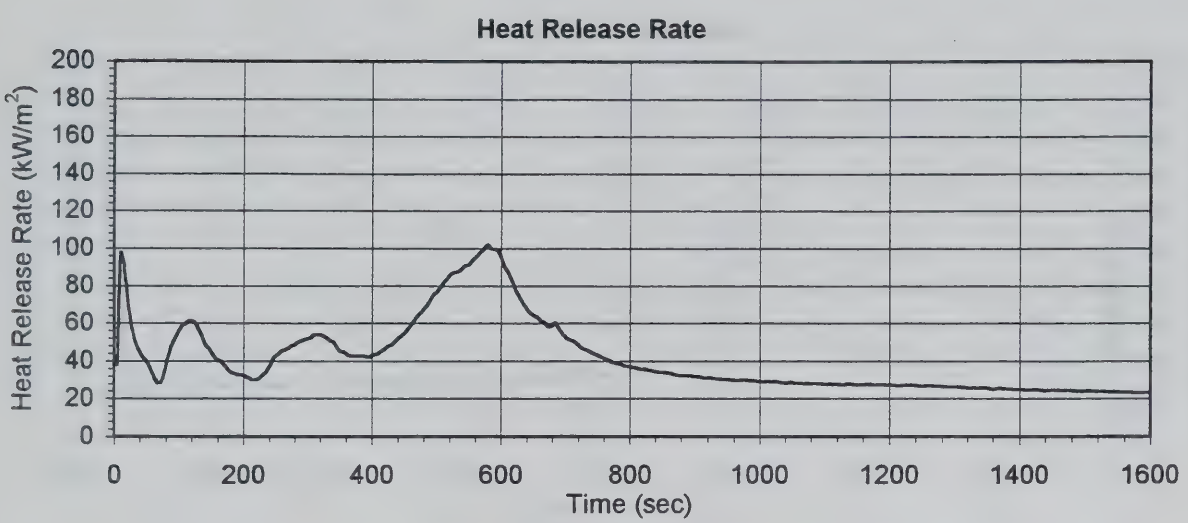


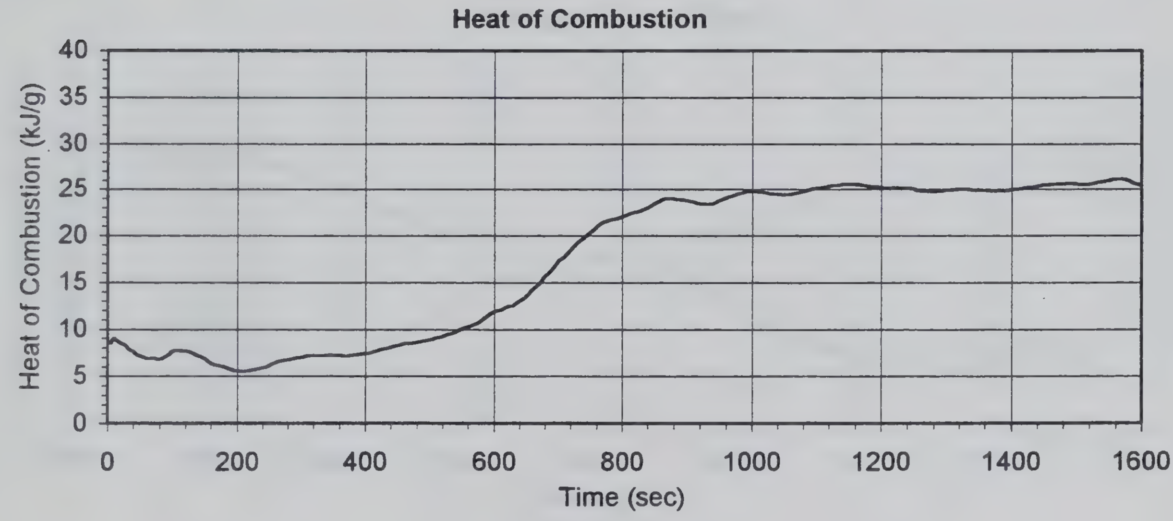


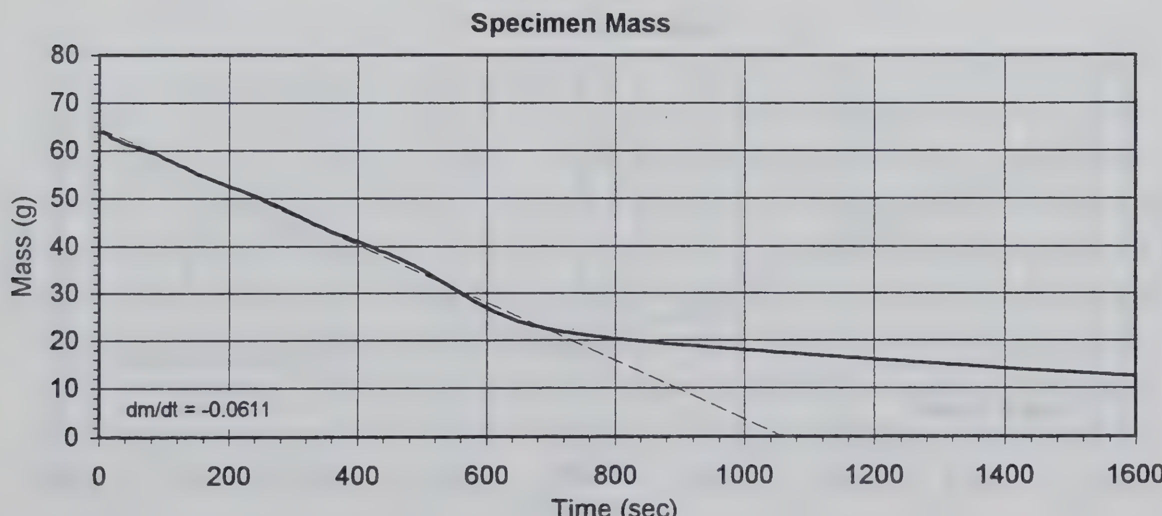


Cone Calorimeter Data R 4.10 F.R. Plywood

40 kW/m^2, Test #4

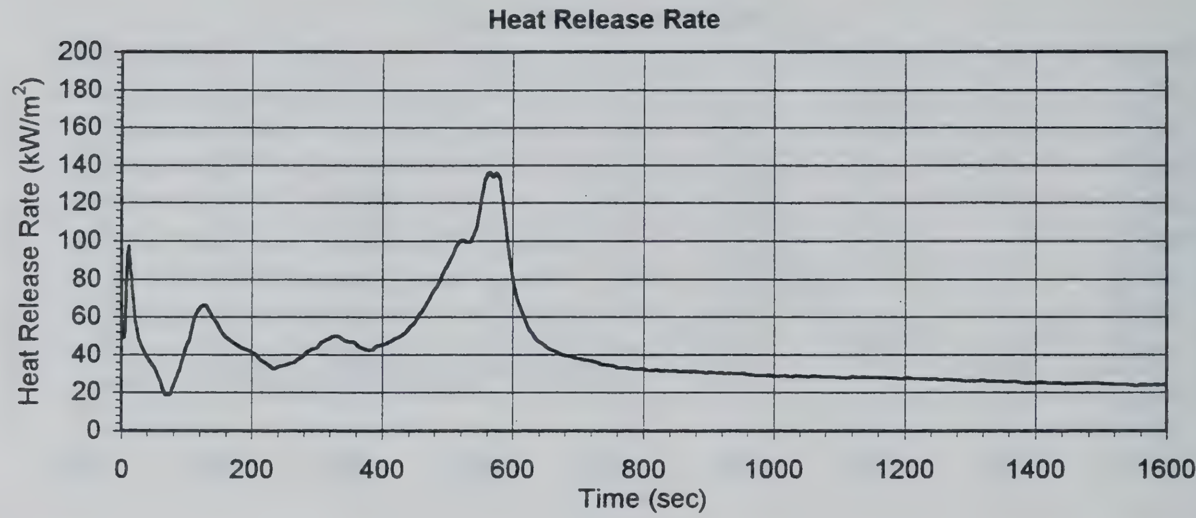


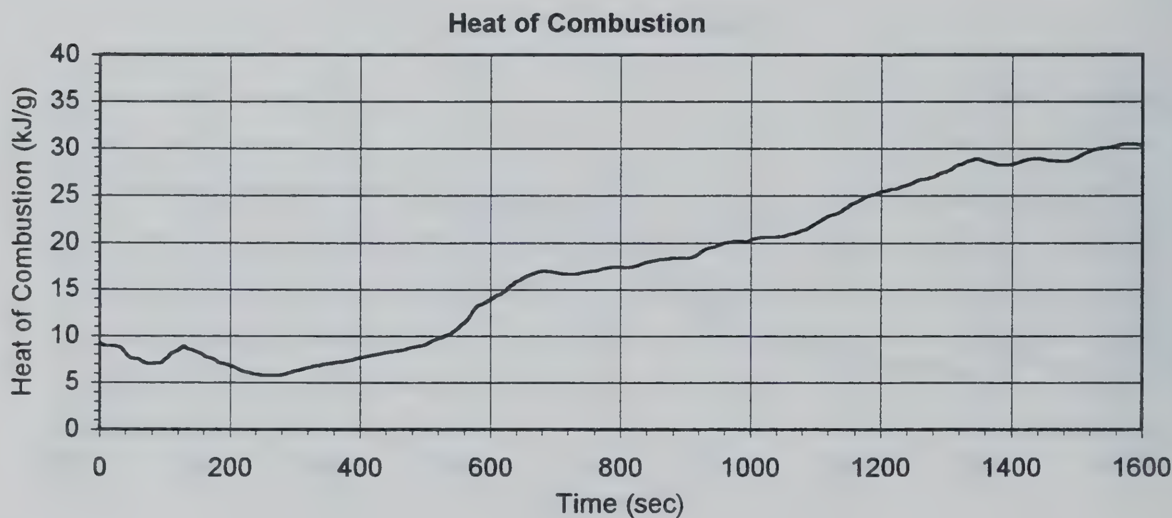


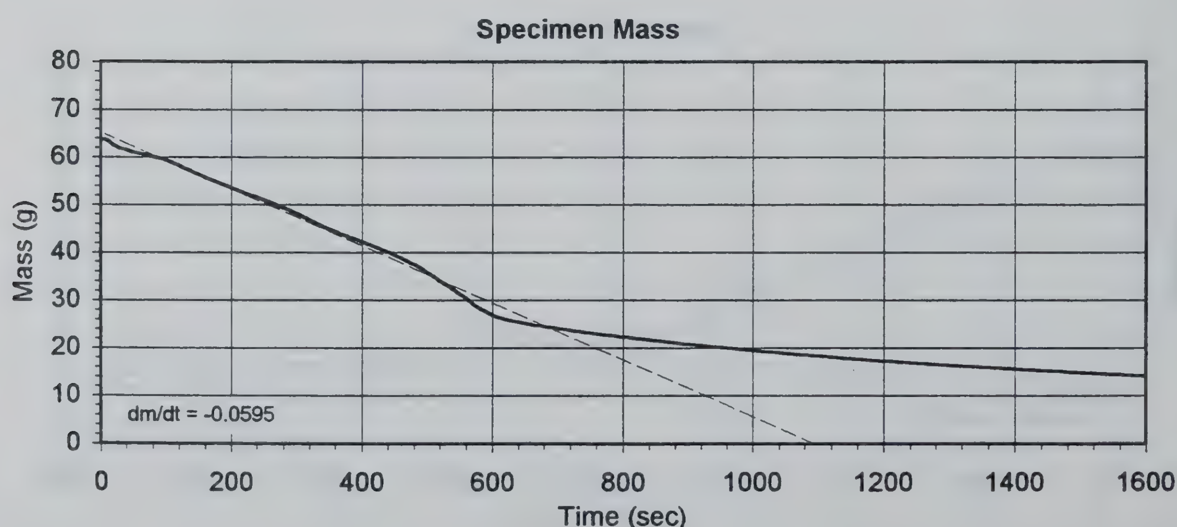


Cone Calorimeter Data R 4.10 F.R. Plywood

40 kW/m^2, Test #5

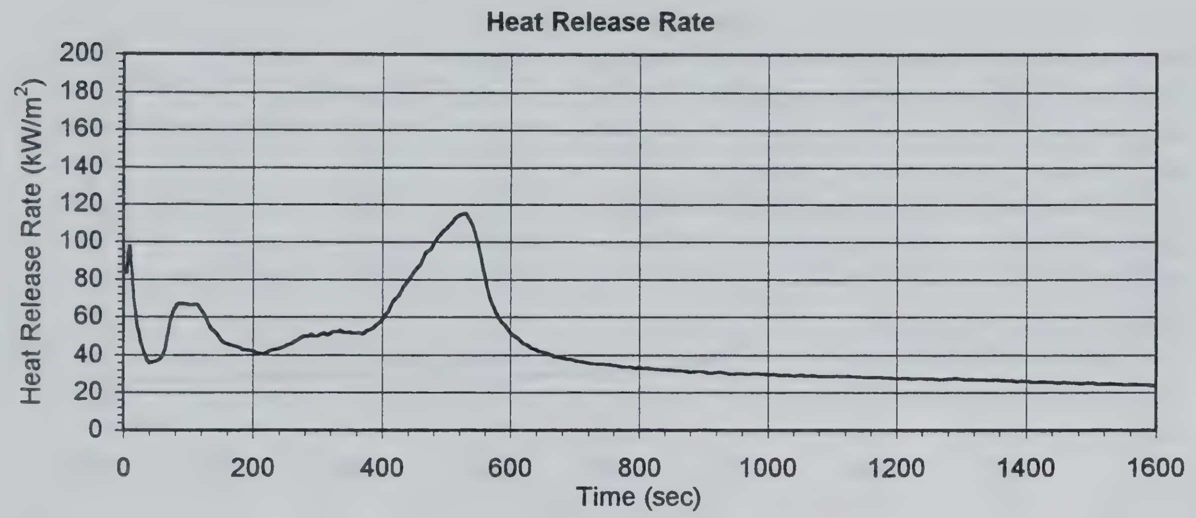


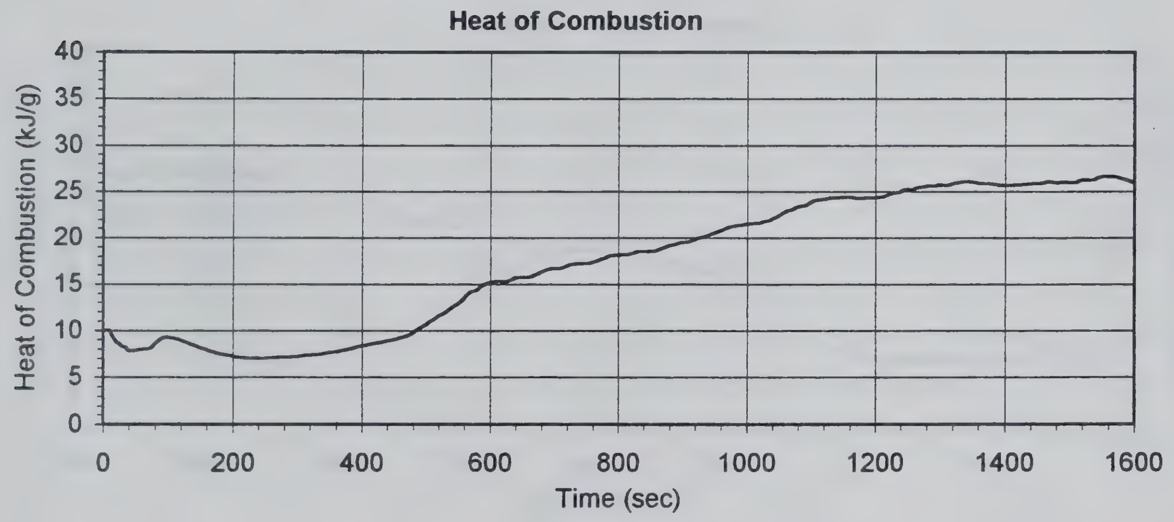


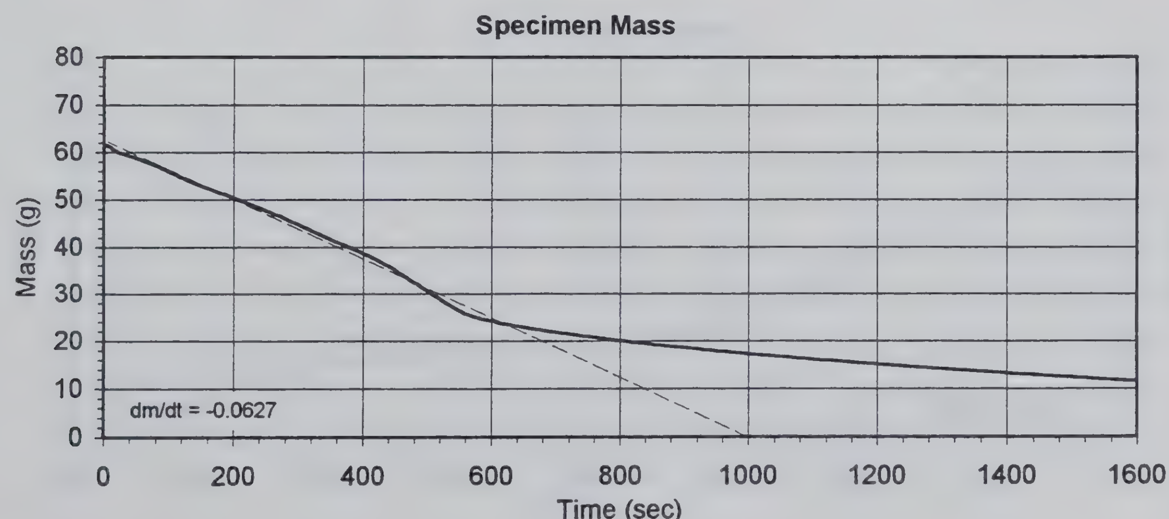


Cone Calorimeter Data R 4.10 F.R. Plywood

50 kW/m^2, Test #1

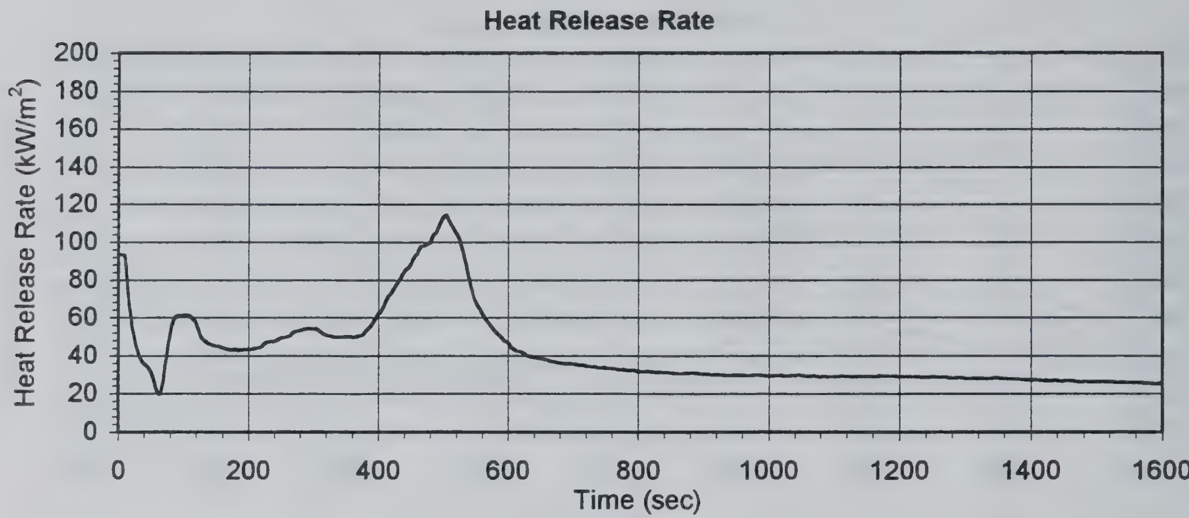


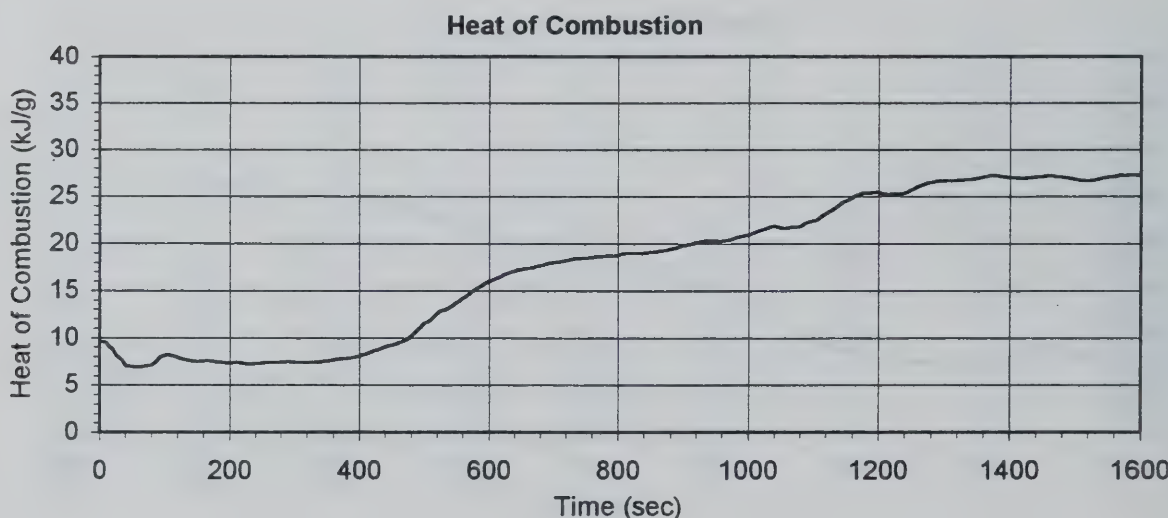


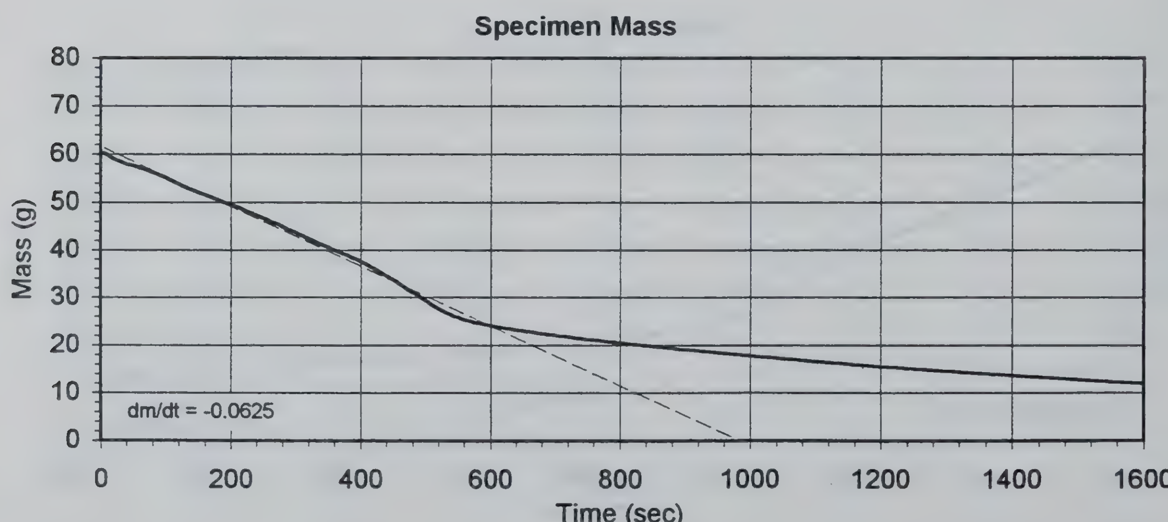


Cone Calorimeter Data R 4.10 F.R. Plywood

50 kW/m^2, Test #2

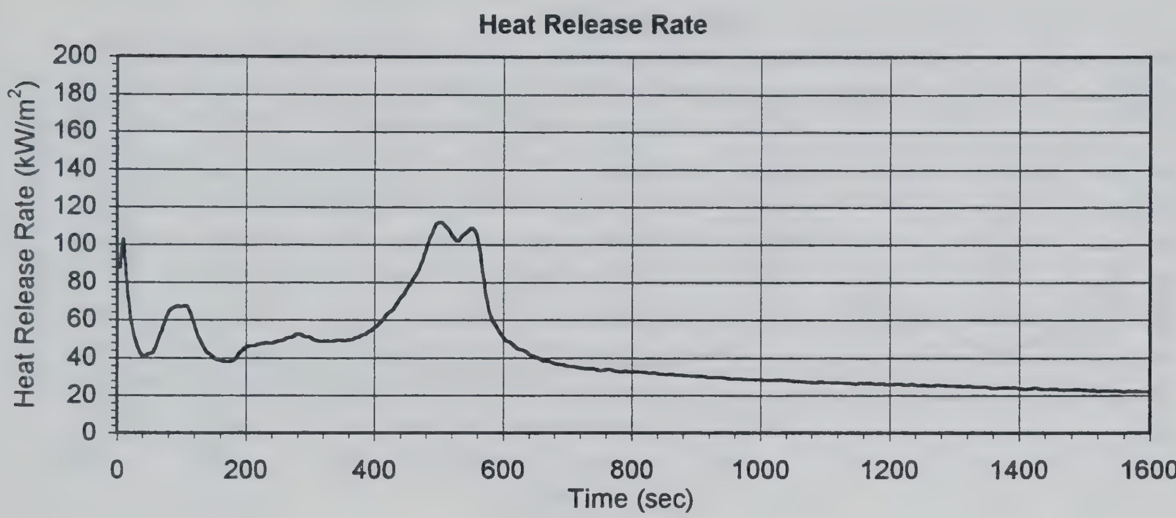


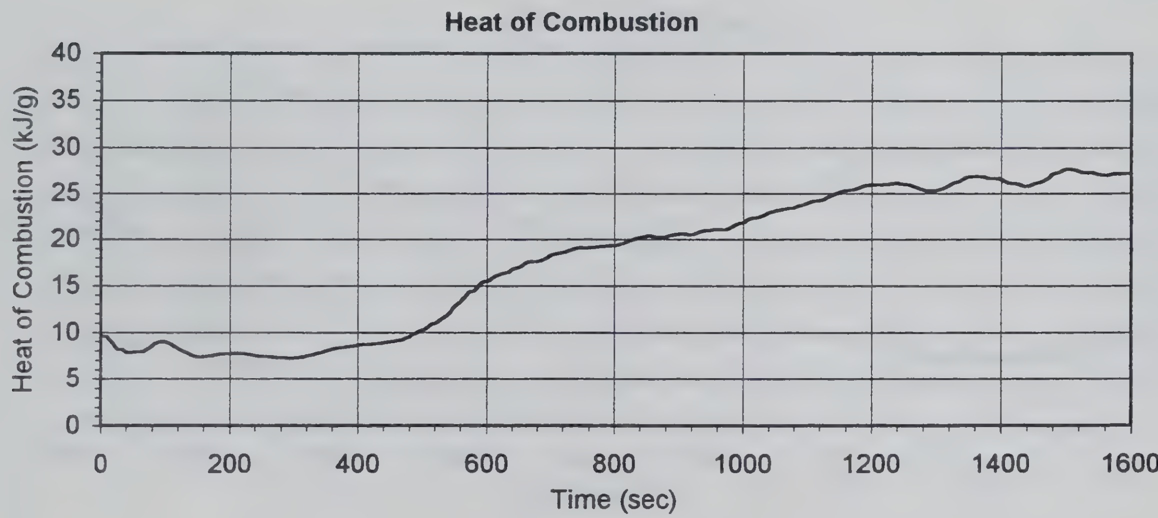


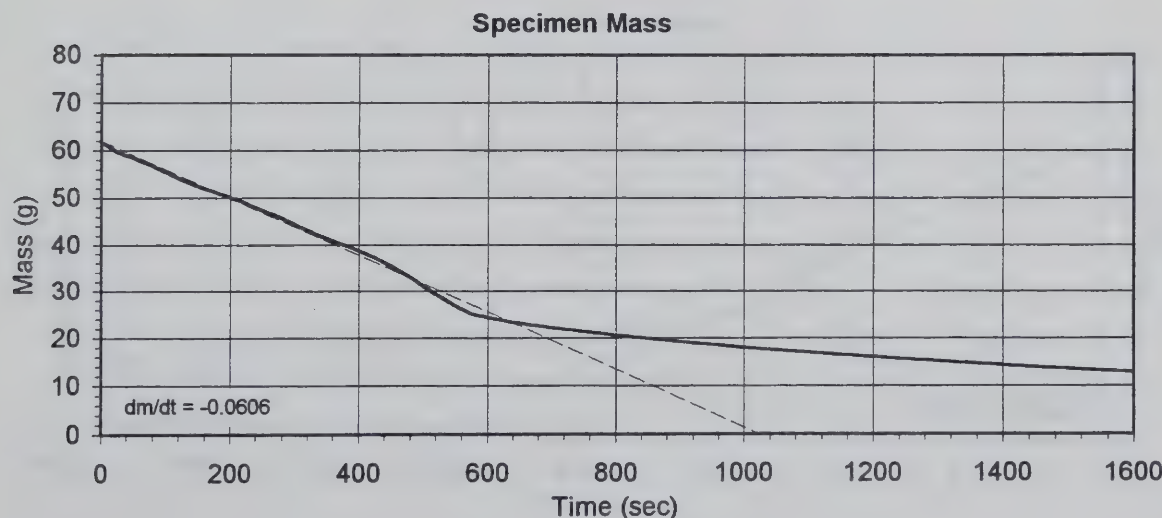


Cone Calorimeter Data R 4.10 F.R. Plywood

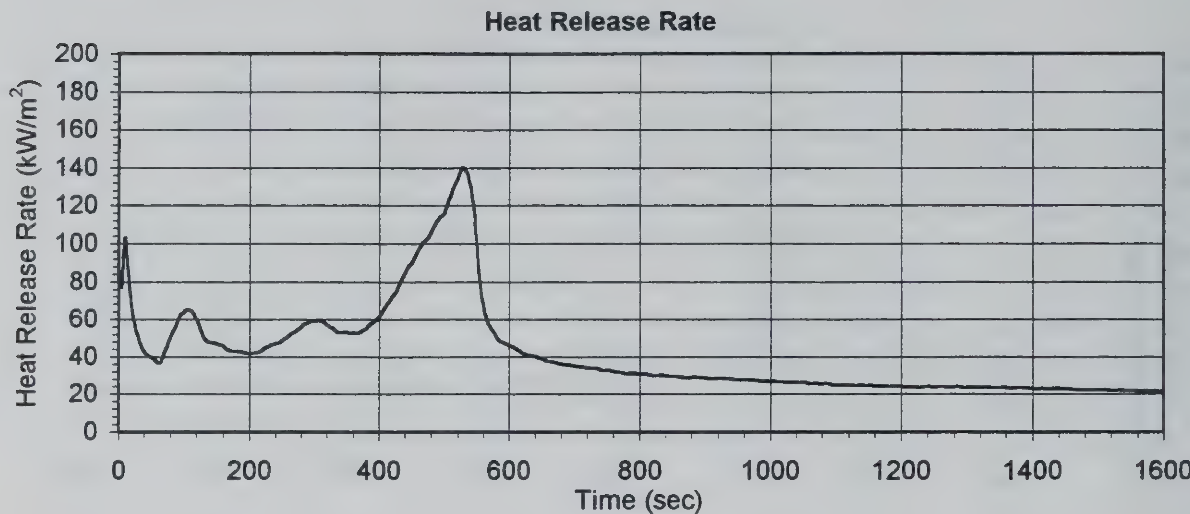
50 kW/m^2, Test #3

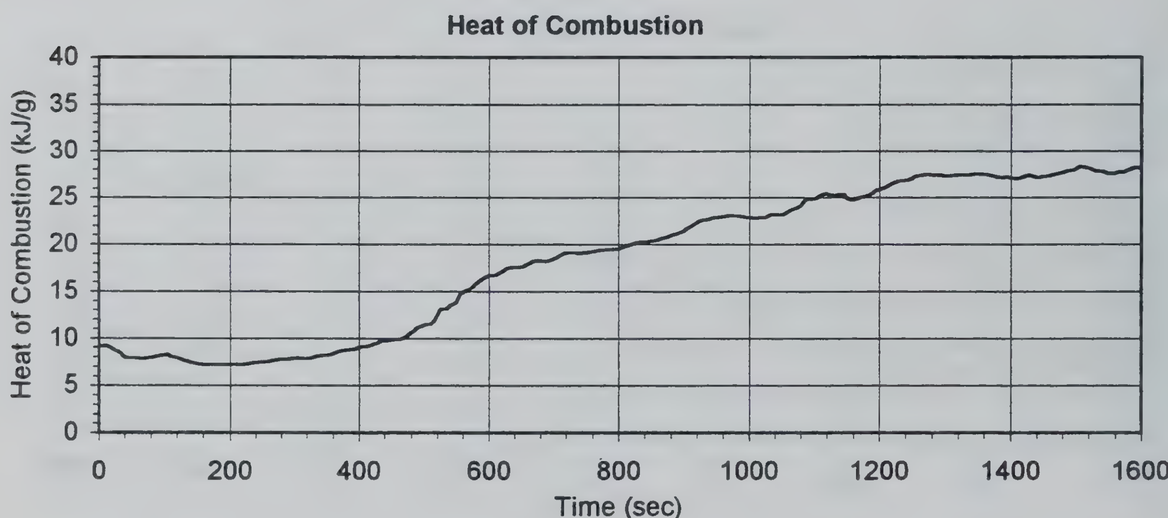


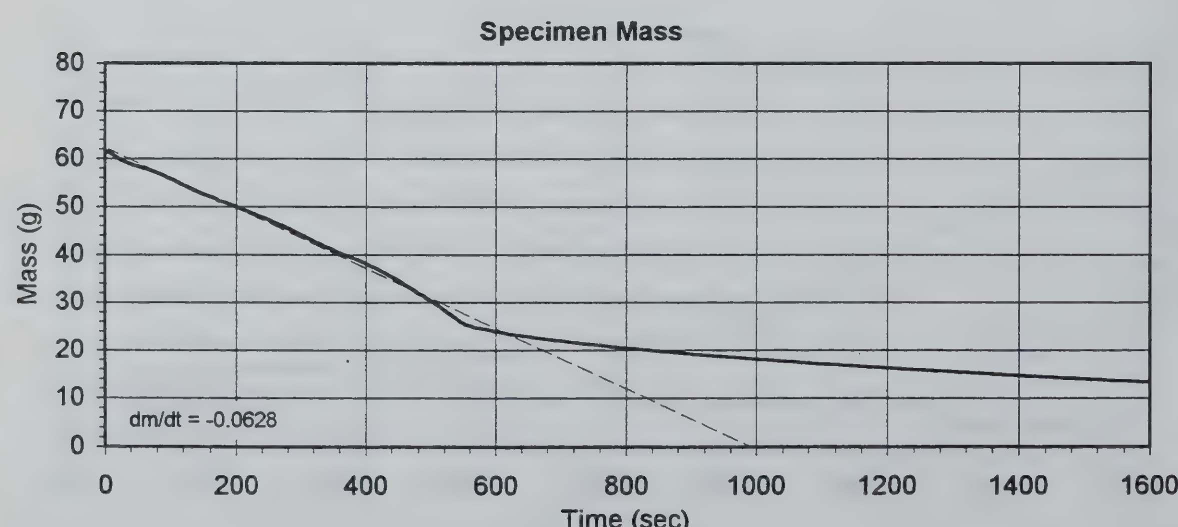




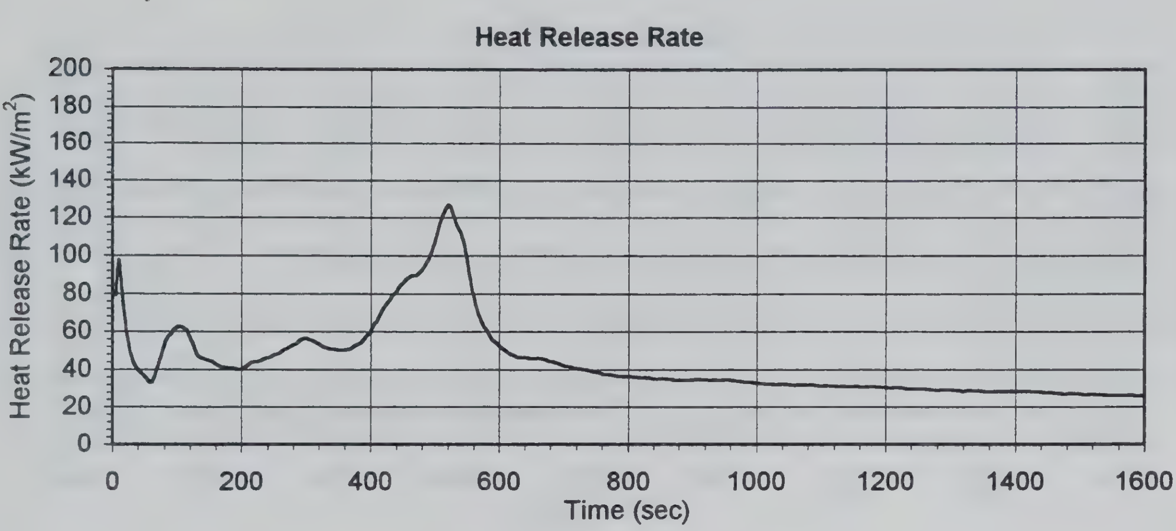
Cone Calorimeter Data R 4.10 F.R. Plywood
50 kW/m², Test #4

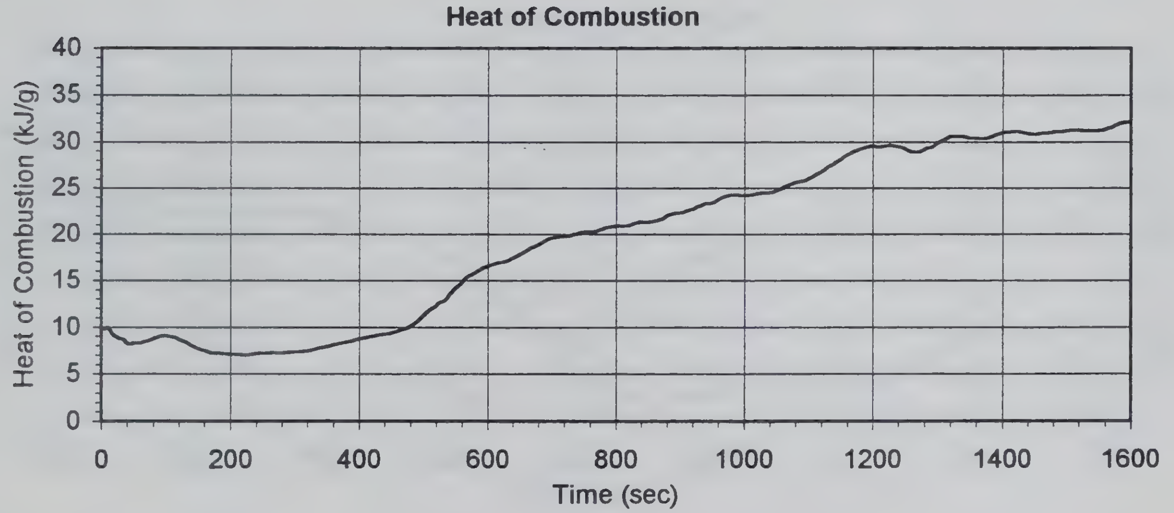


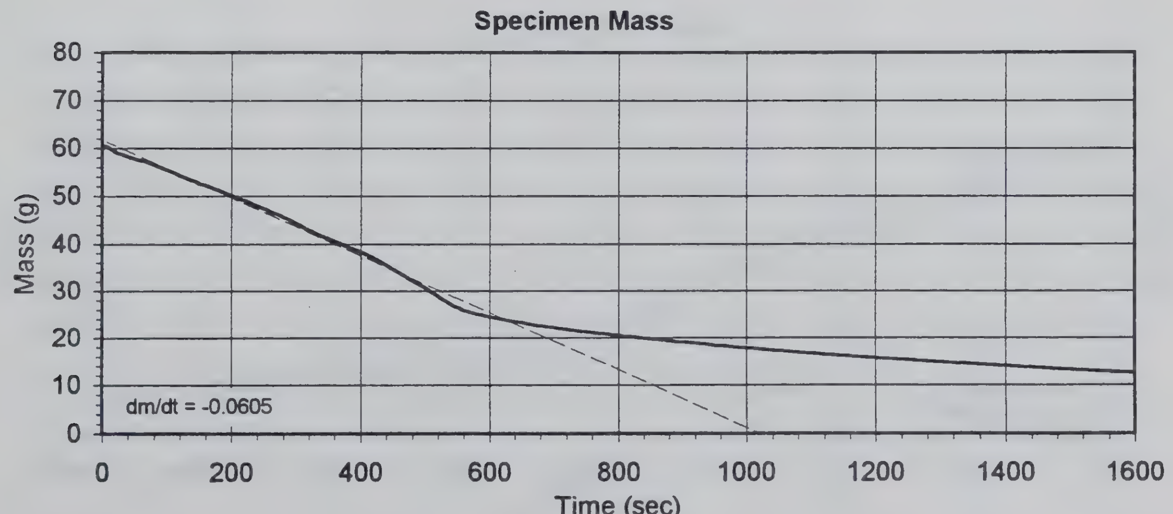




Cone Calorimeter Data R 4.10 F.R. Plywood
50 kW/m^2, Test #5

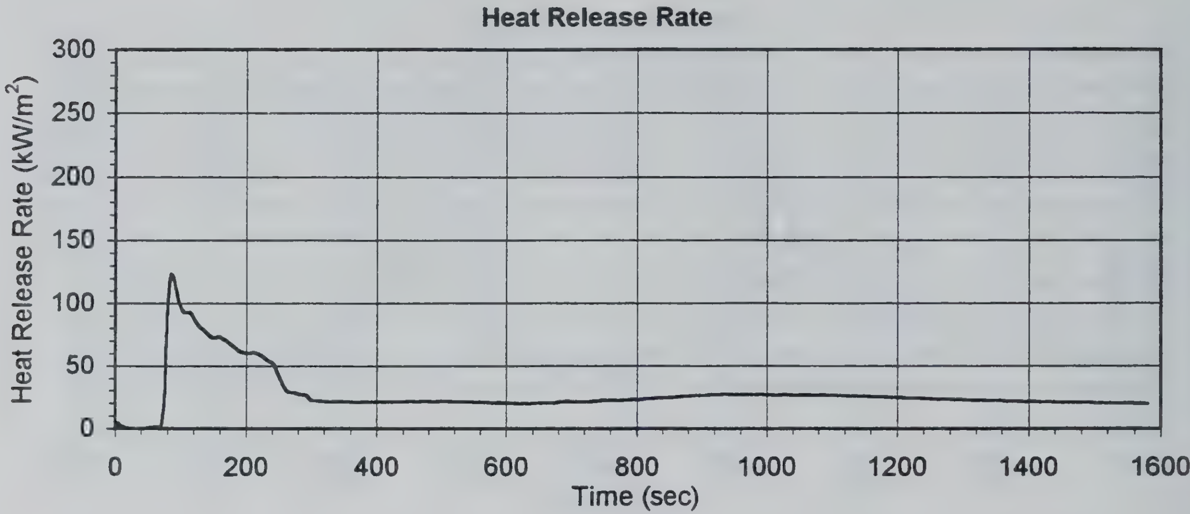


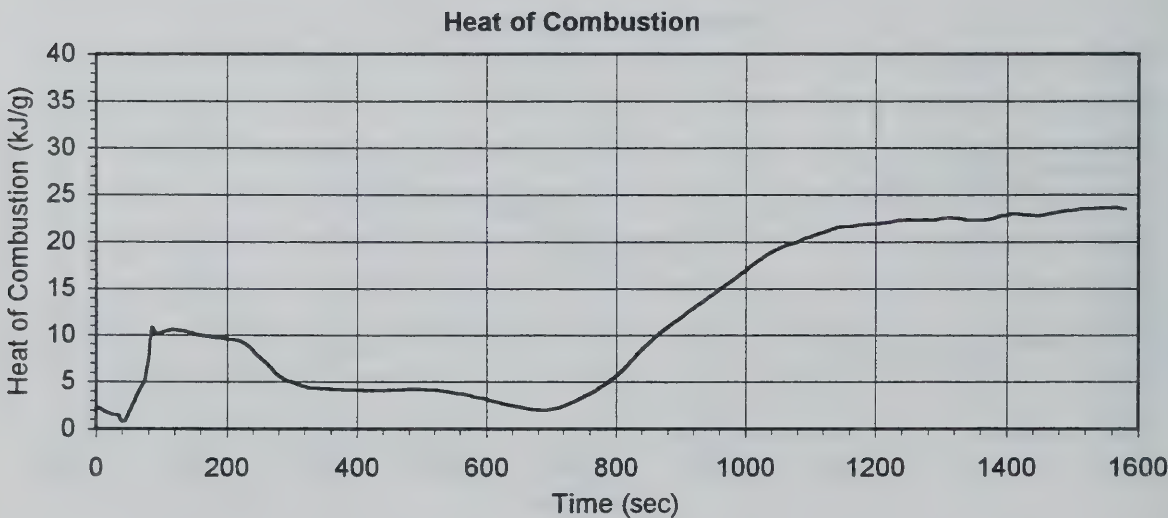


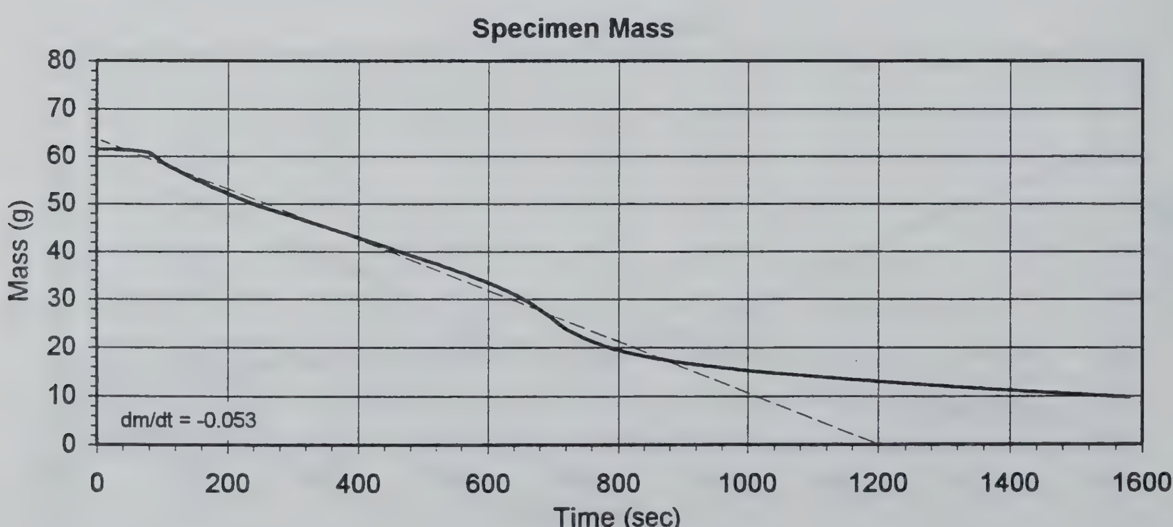


Cone Calorimeter Data R 4.11 Normal Plywood

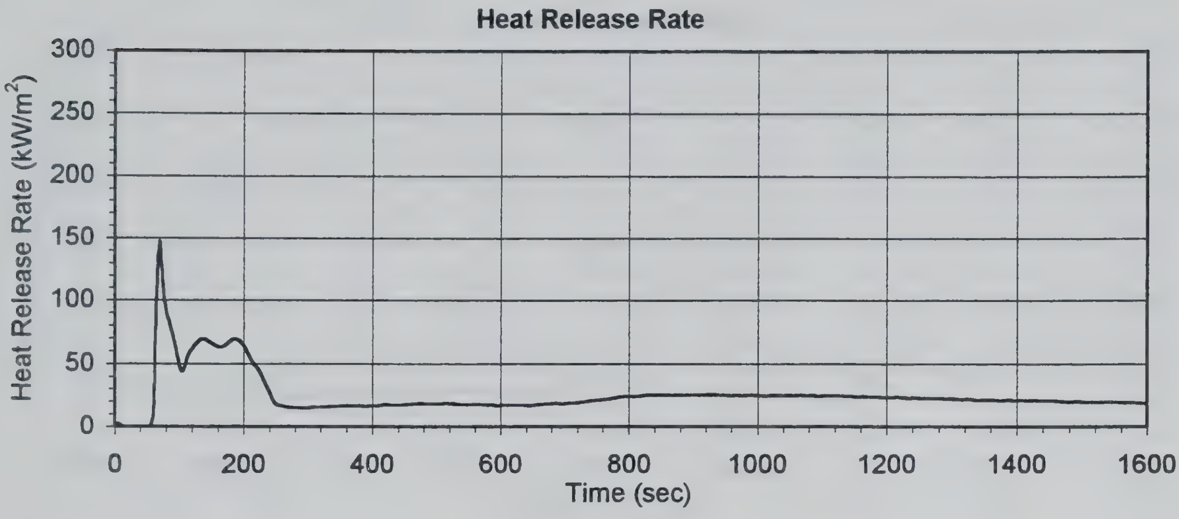
25 kW/m², Test #1

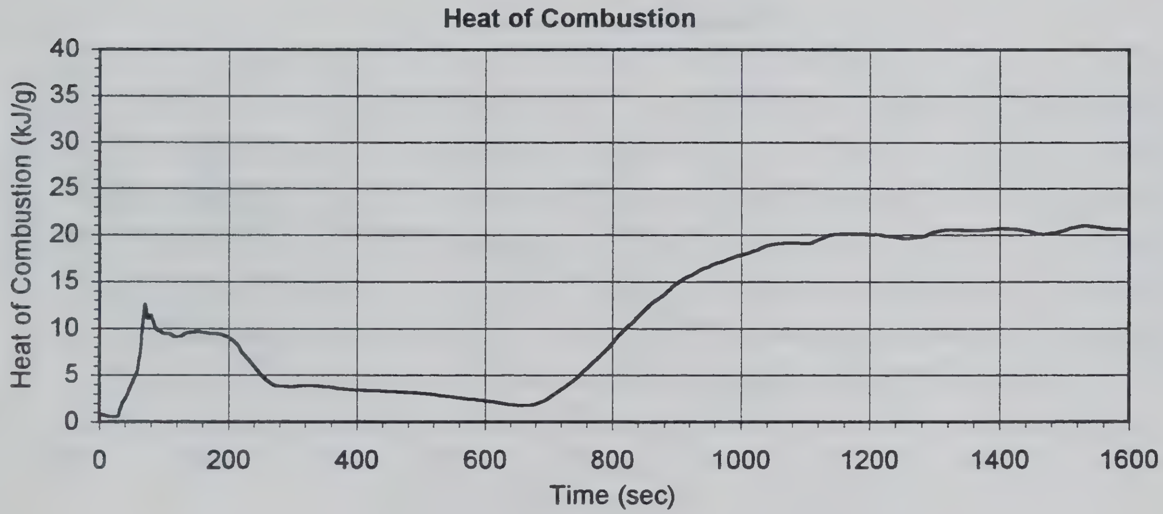


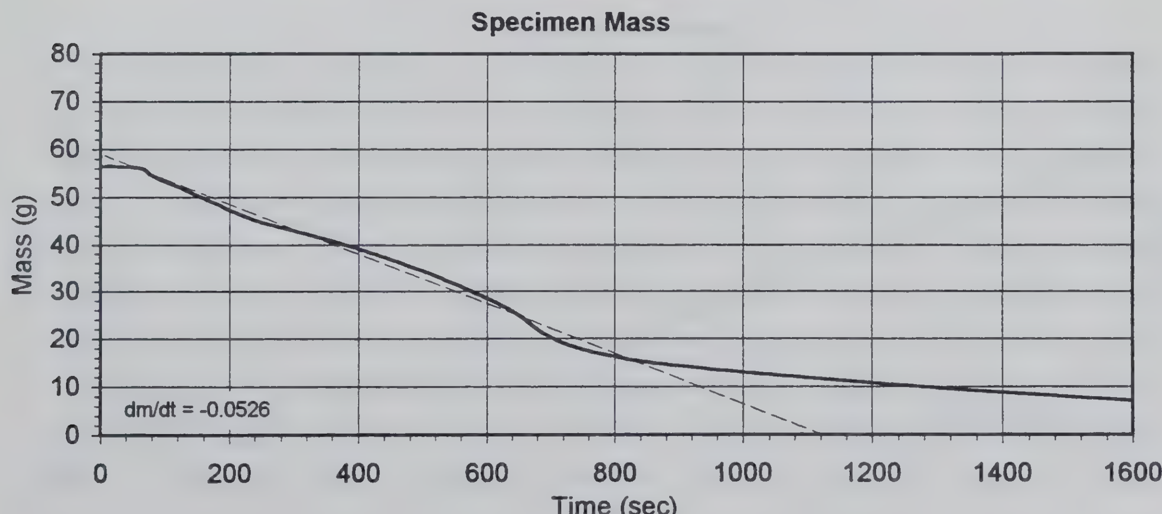




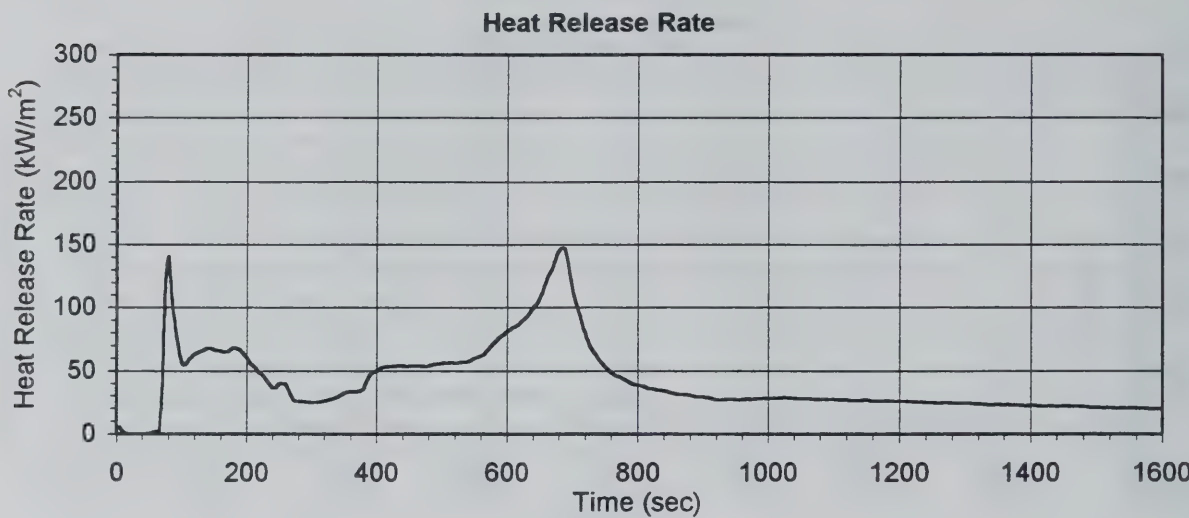
Cone Calorimeter Data R 4.11 Normal Plywood
25 kW/m^2, Test #2

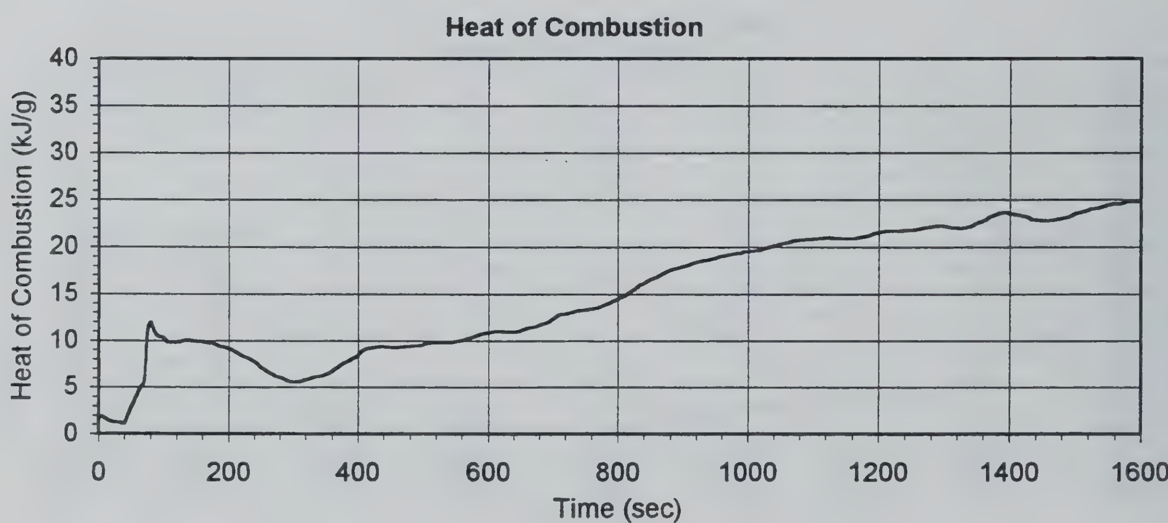


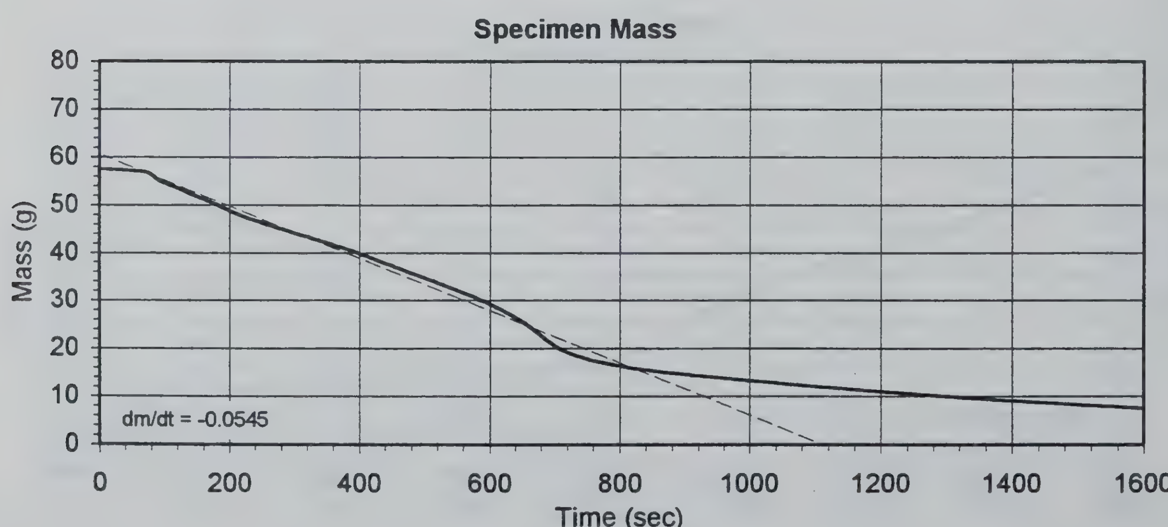




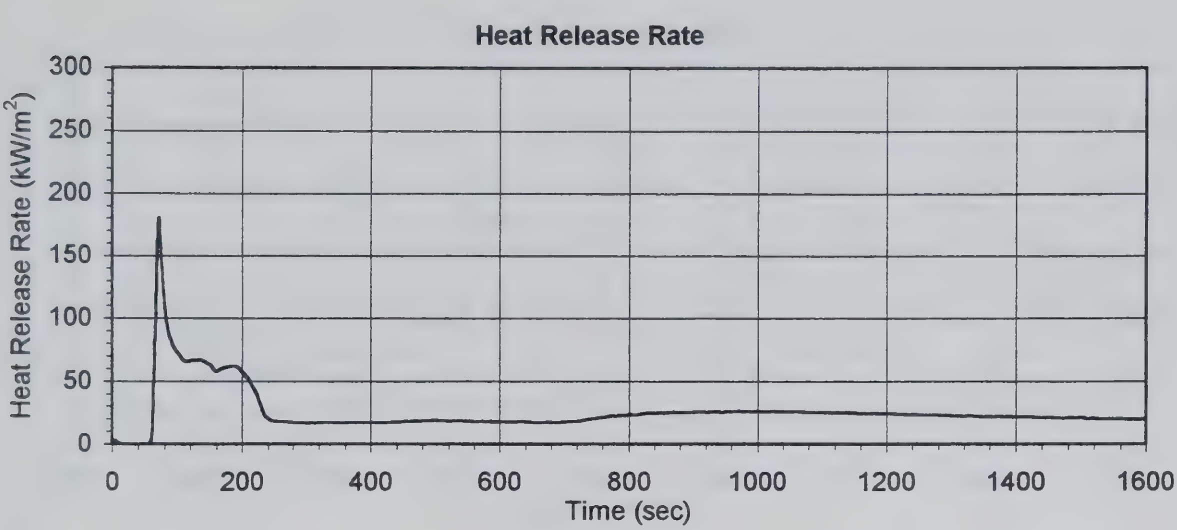
Cone Calorimeter Data R 4.11 Normal Plywood
25 kW/m^2, Test #3

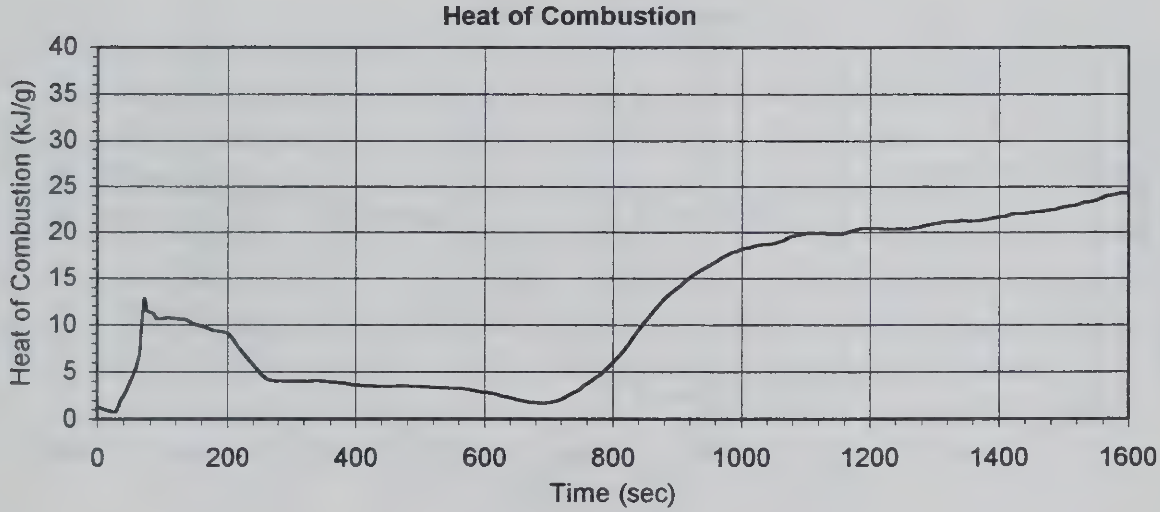


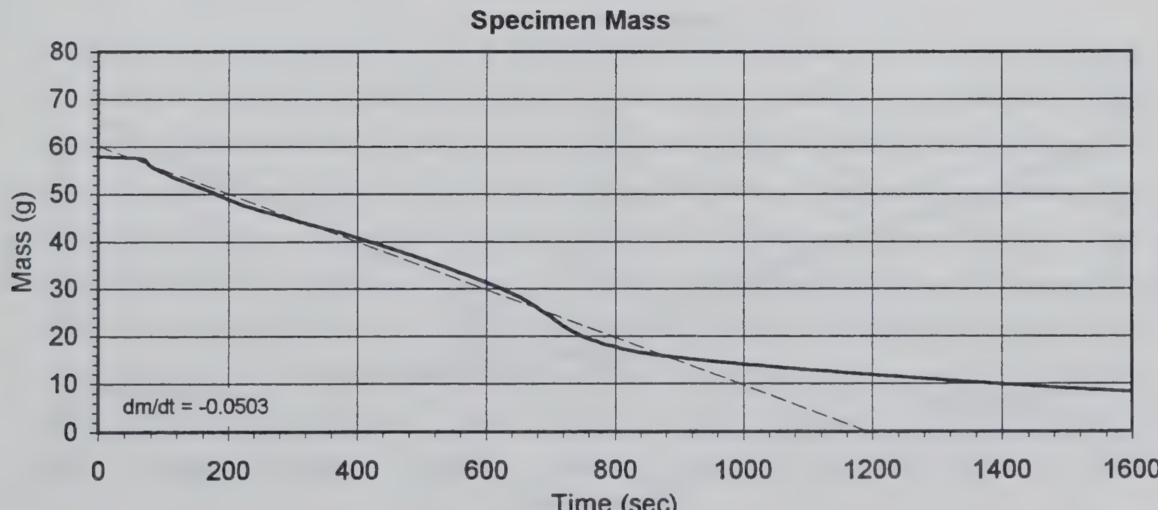




Cone Calorimeter Data R 4.11 Normal Plywood
25 kW/m^2, Test #4



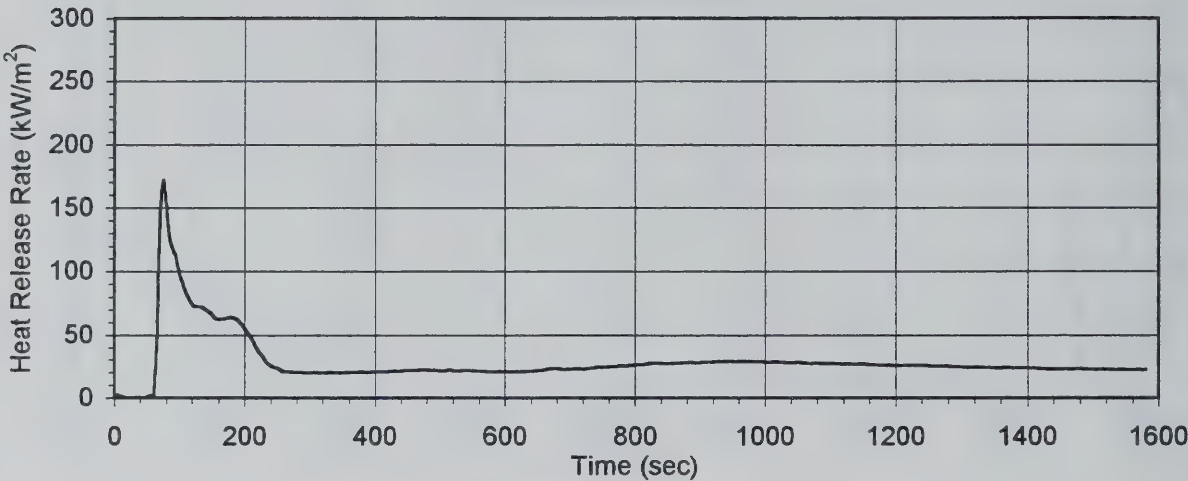




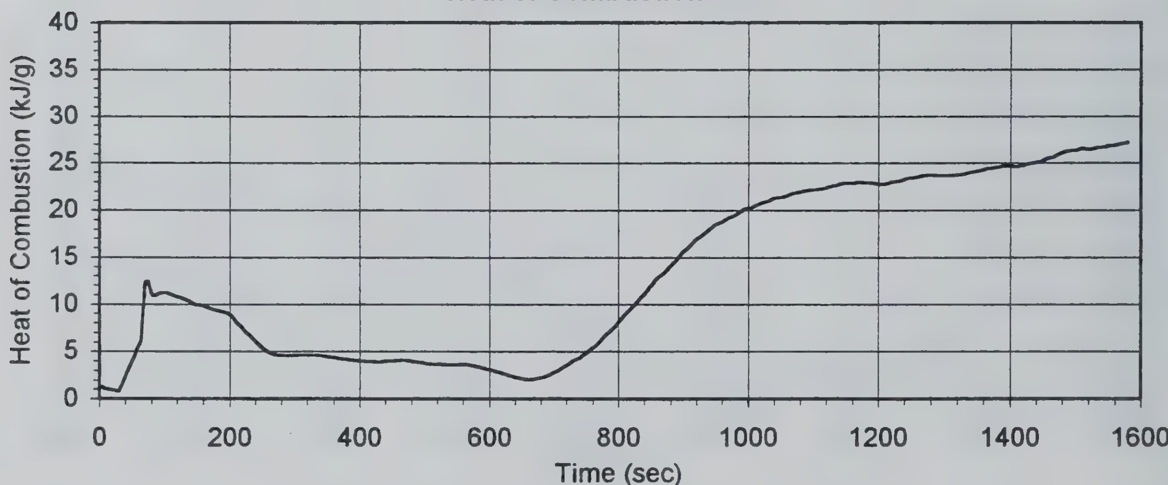
Cone Calorimeter Data R 4.11 Normal Plywood

25 kW/m^2, Test #5

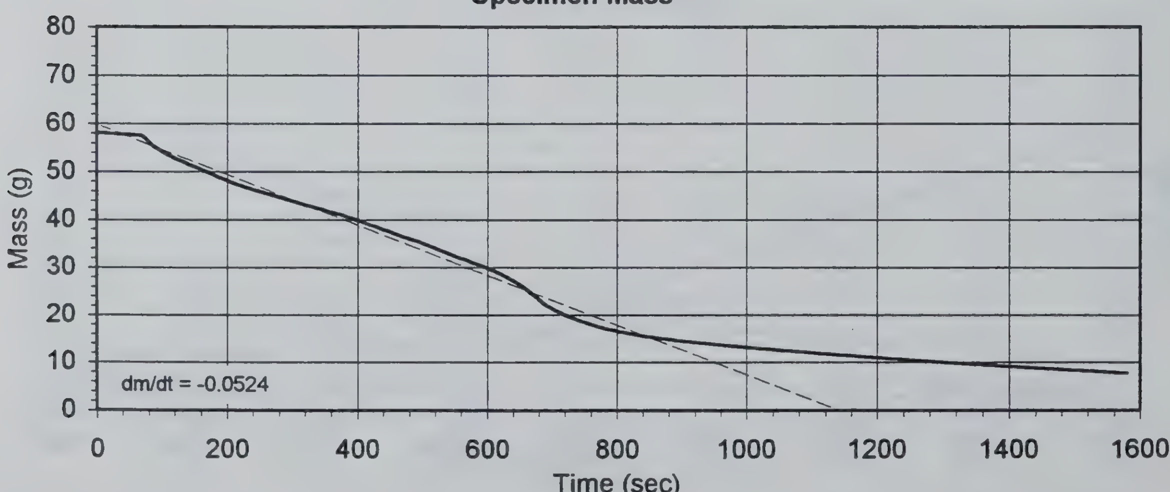
Heat Release Rate



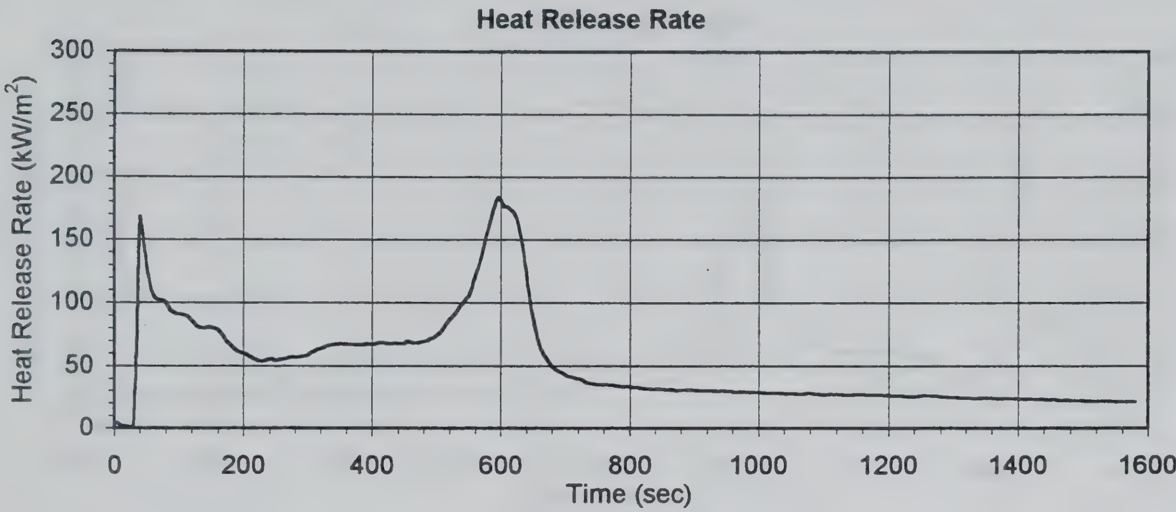
Heat of Combustion

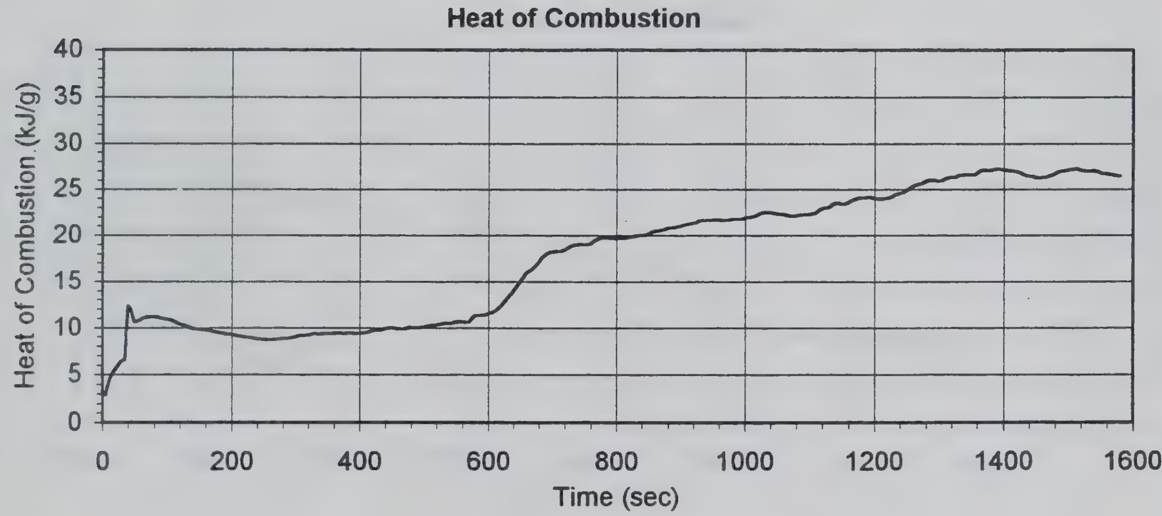


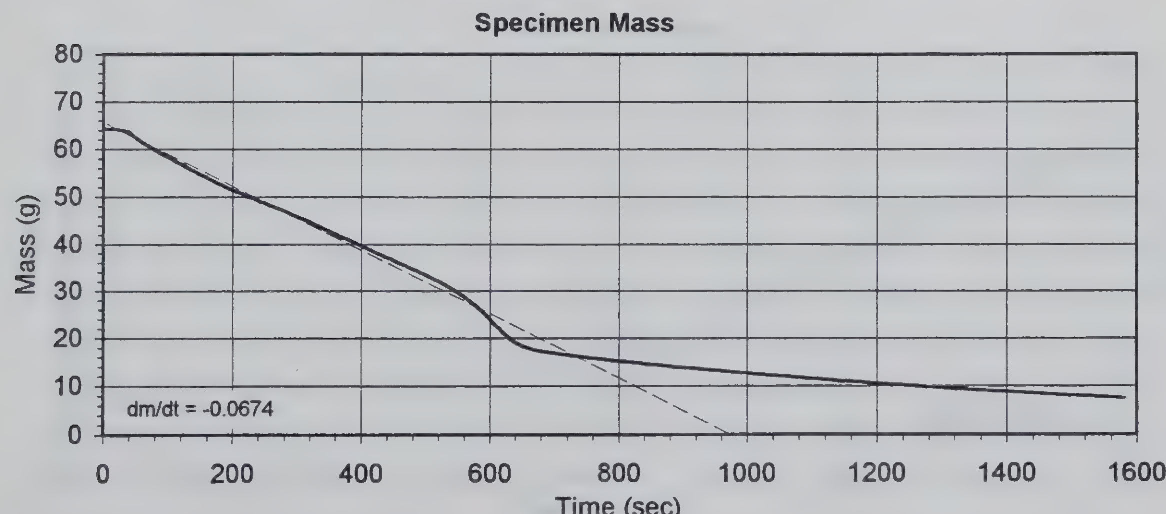
Specimen Mass



Cone Calorimeter Data R 4.11 Normal Plywood
35 kW/m^2, Test #1

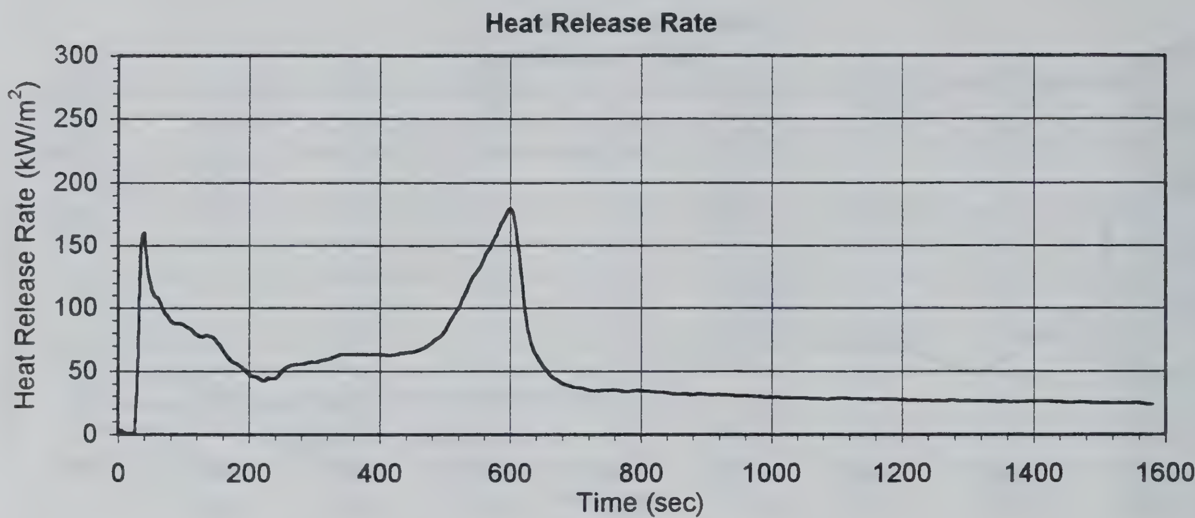


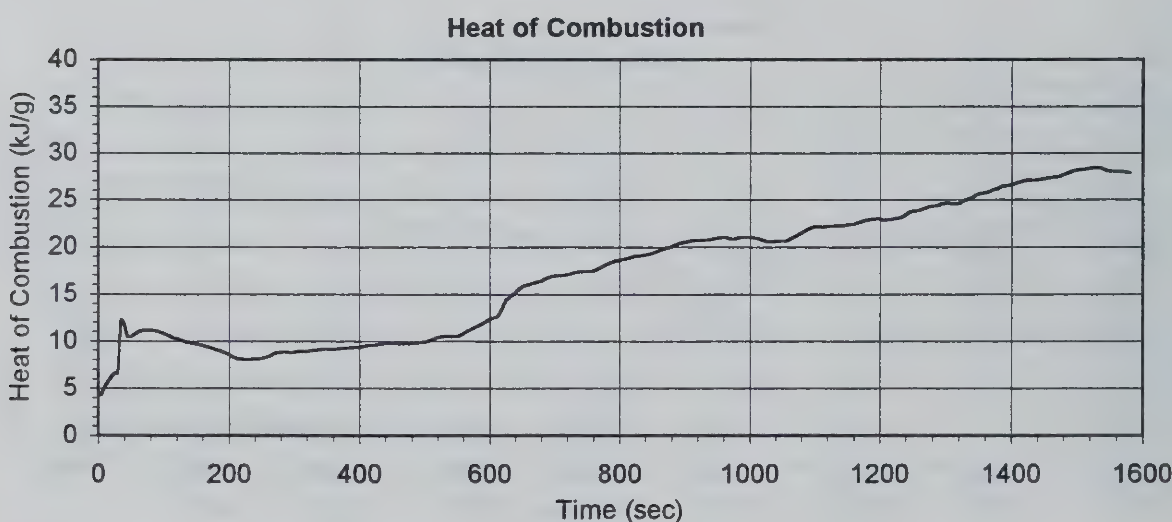


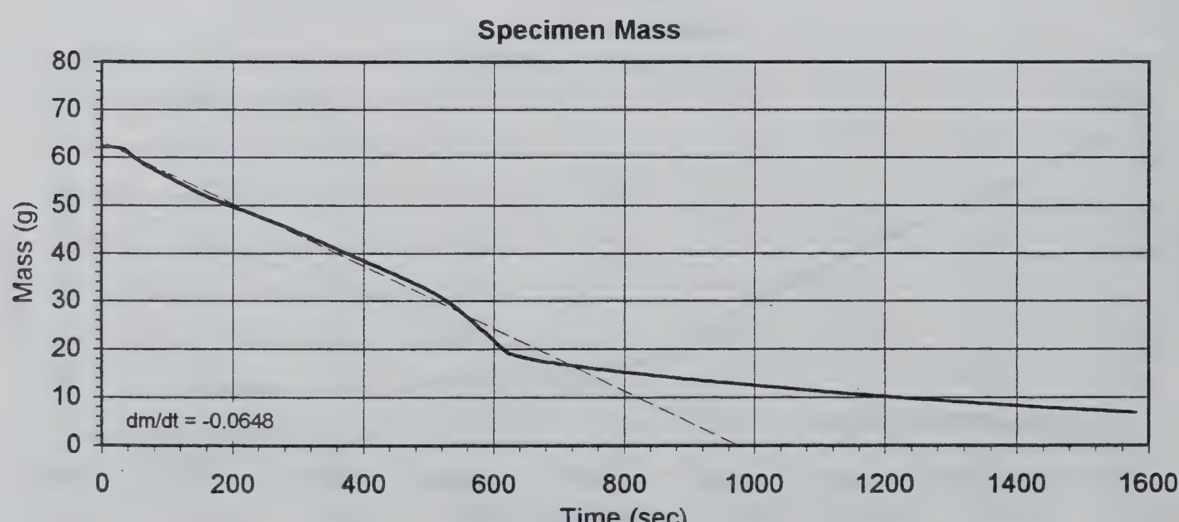


Cone Calorimeter Data R 4.11 Normal Plywood

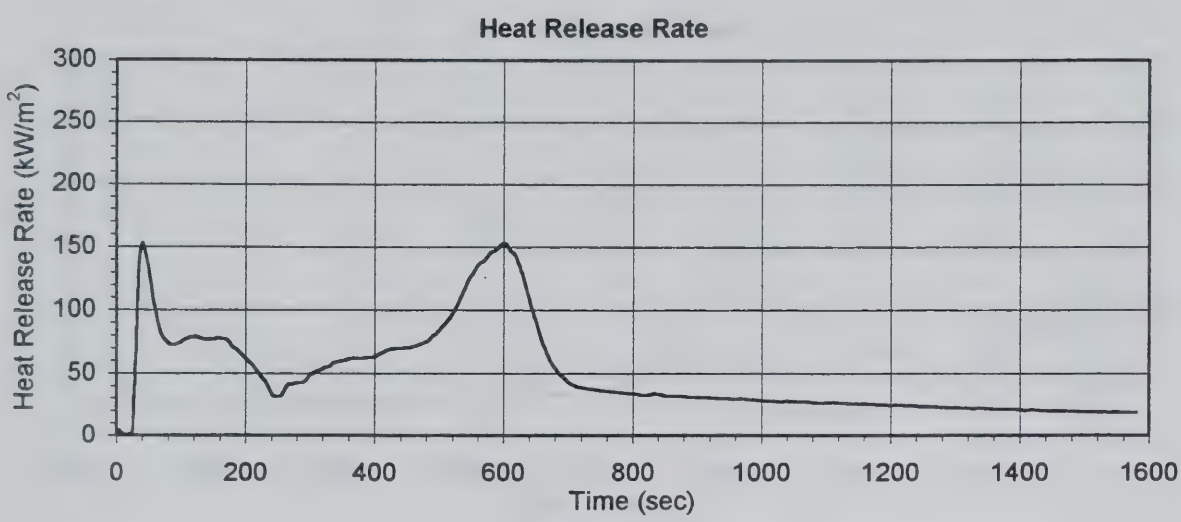
35 kW/m², Test #2

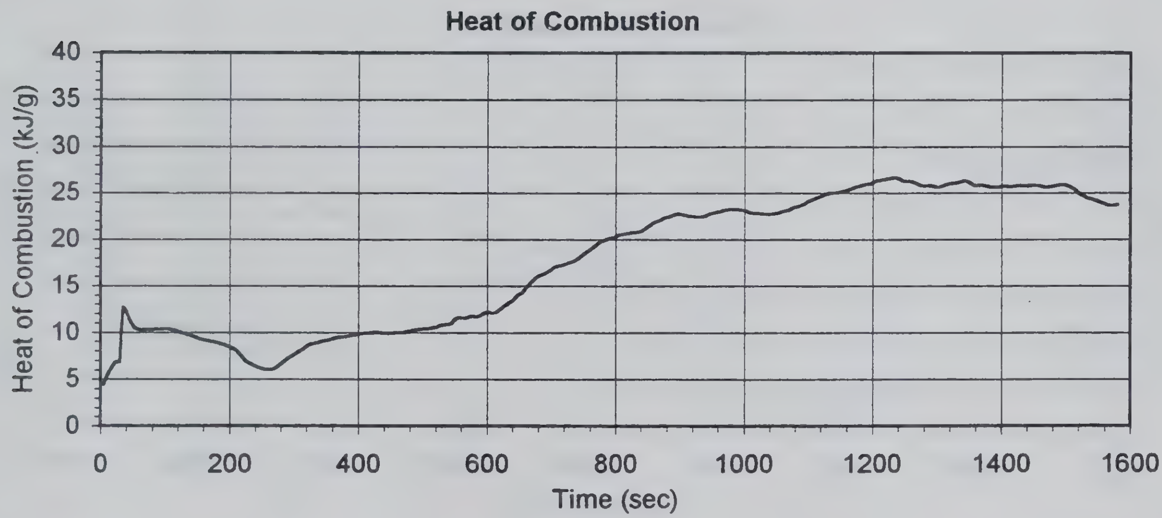


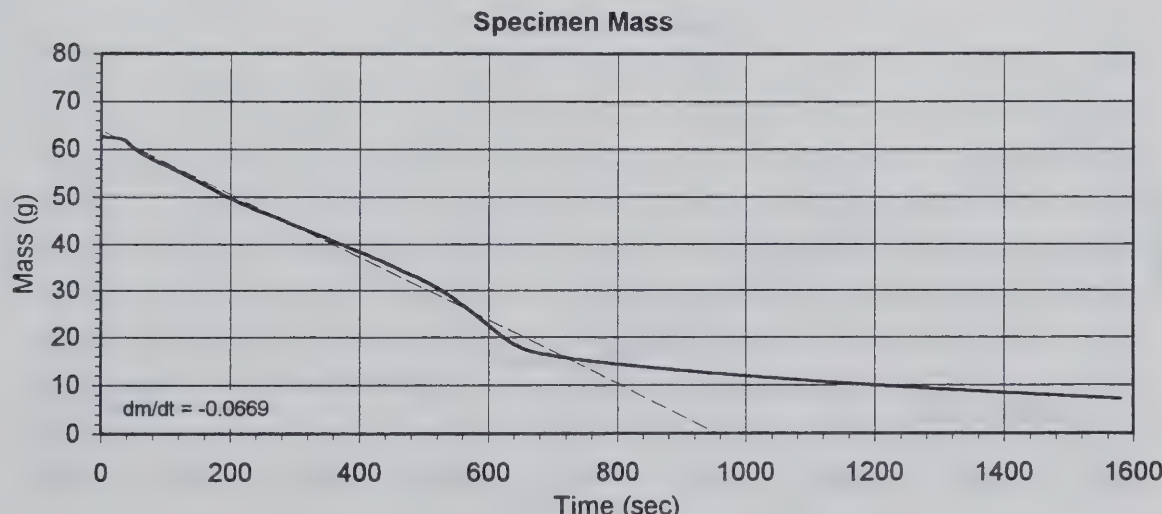




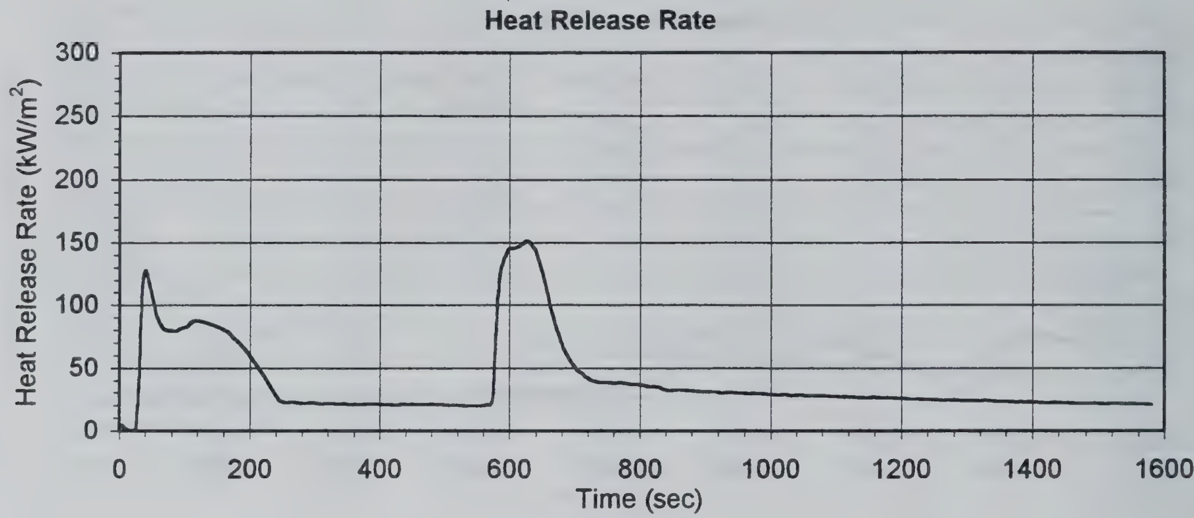
Cone Calorimeter Data R 4.11 Normal Plywood
35 kW/m^2, Test #3

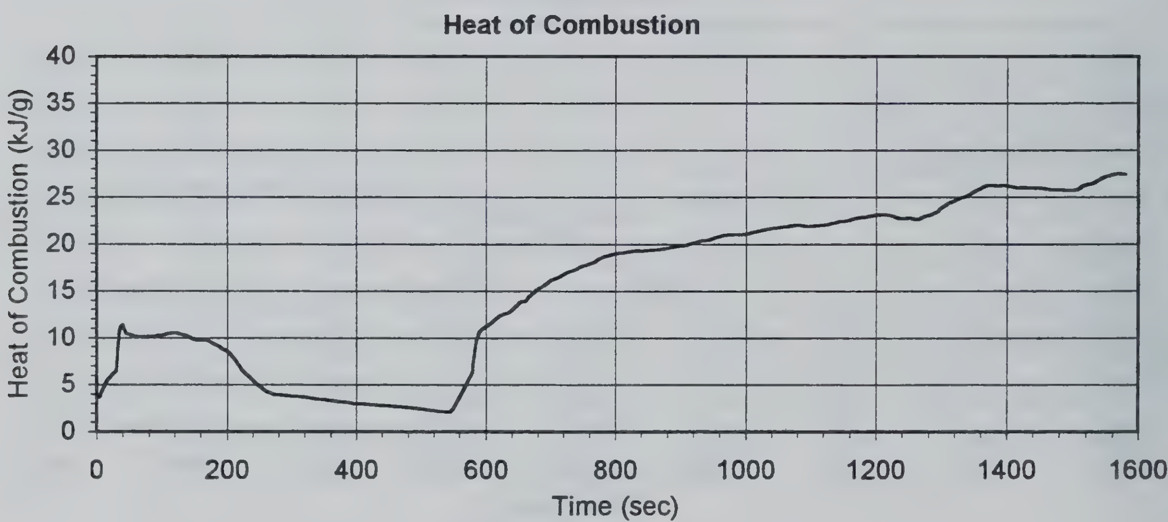


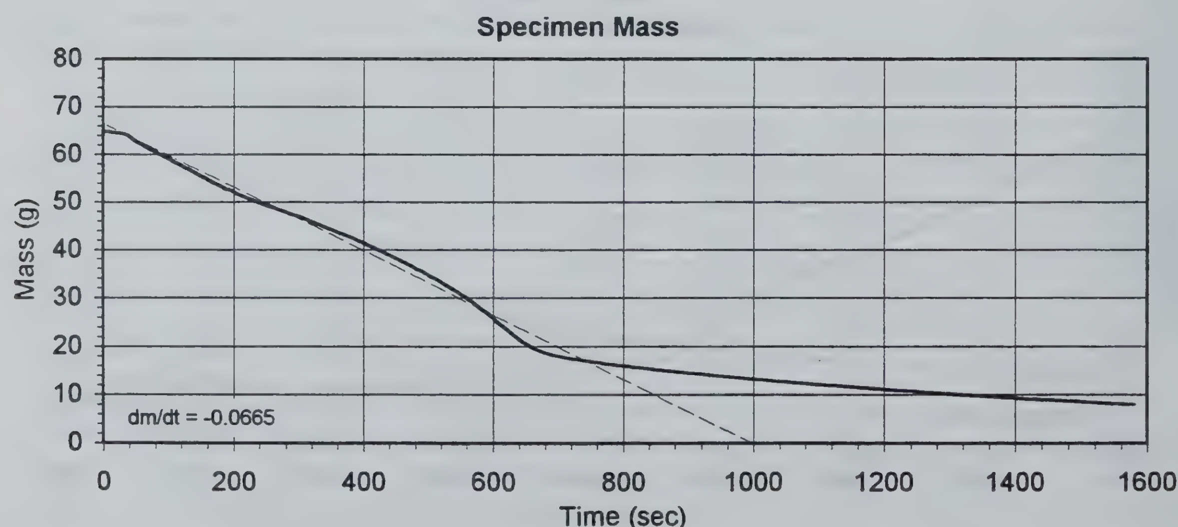




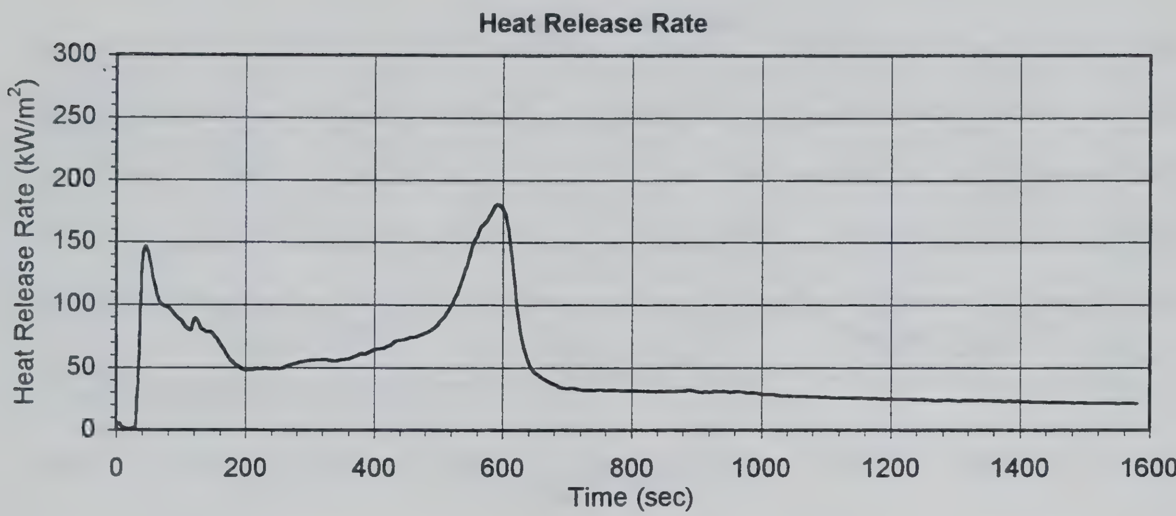
Cone Calorimeter Data R 4.11 Normal Plywood
35 kW/m^2, Test #4

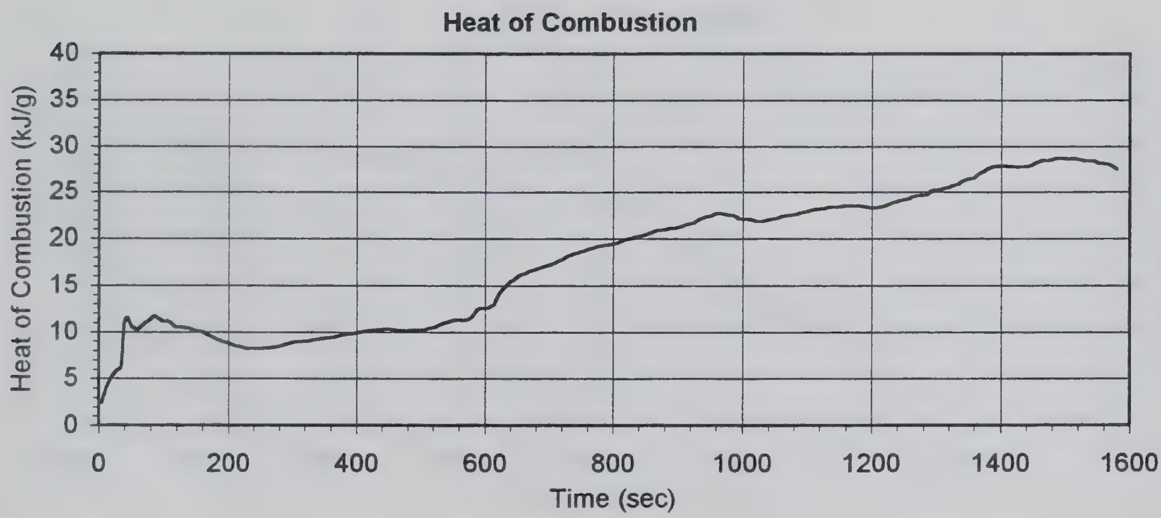


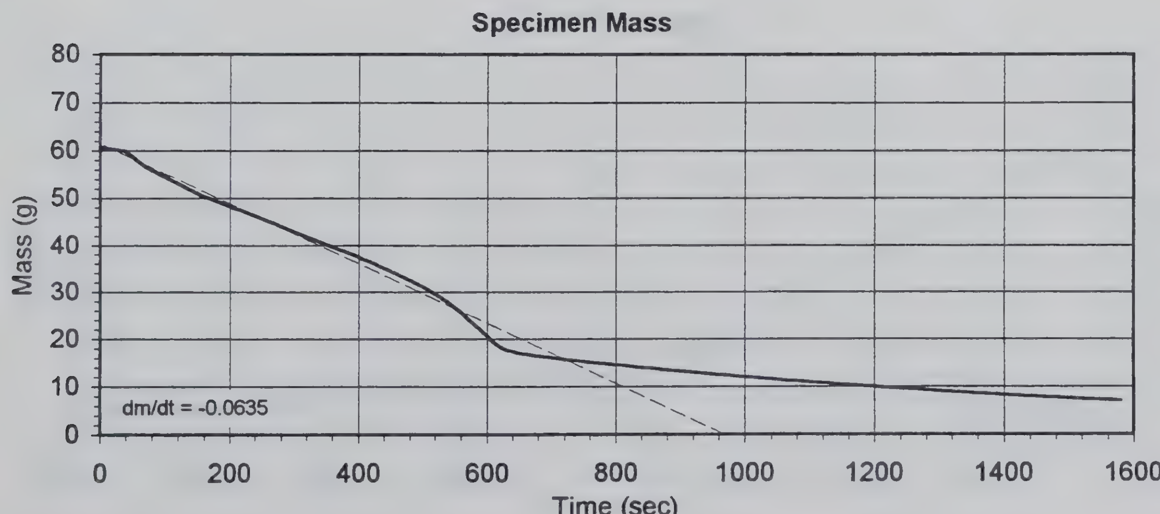




Cone Calorimeter Data R 4.11 Normal Plywood
35 kW/m^2, Test #5

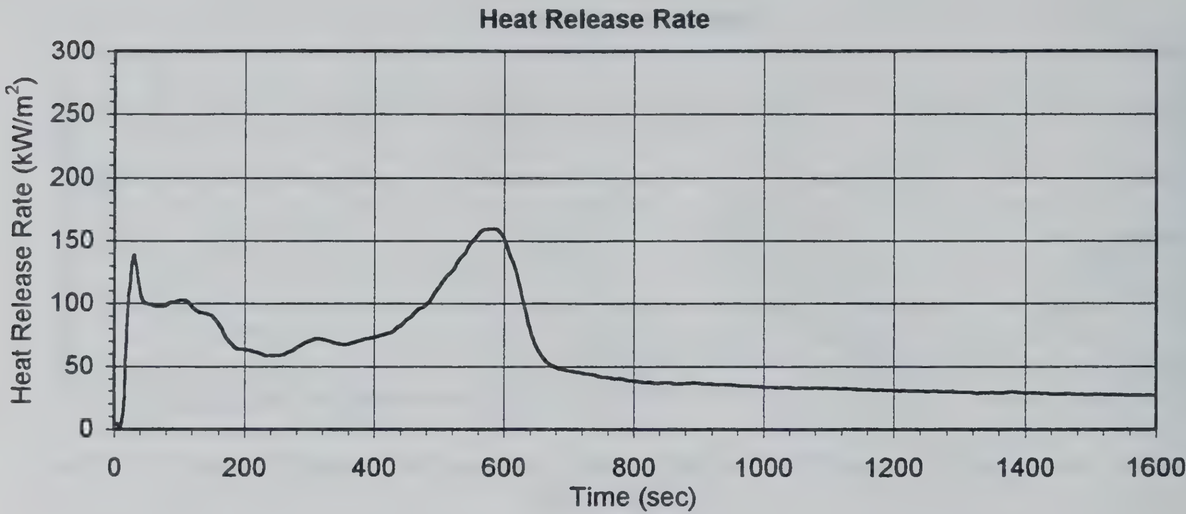


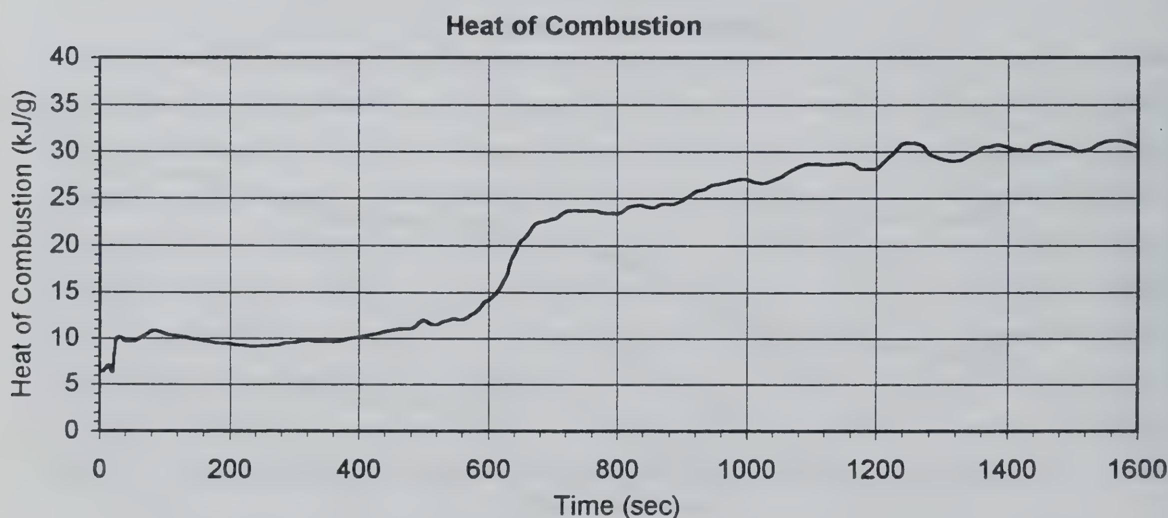


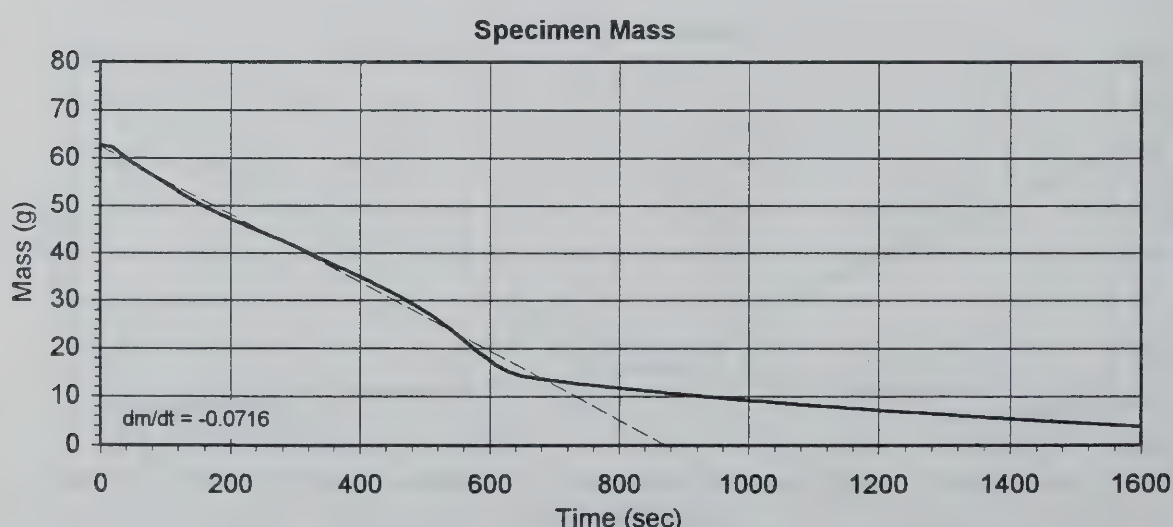


Cone Calorimeter Data R 4.11 Normal Plywood

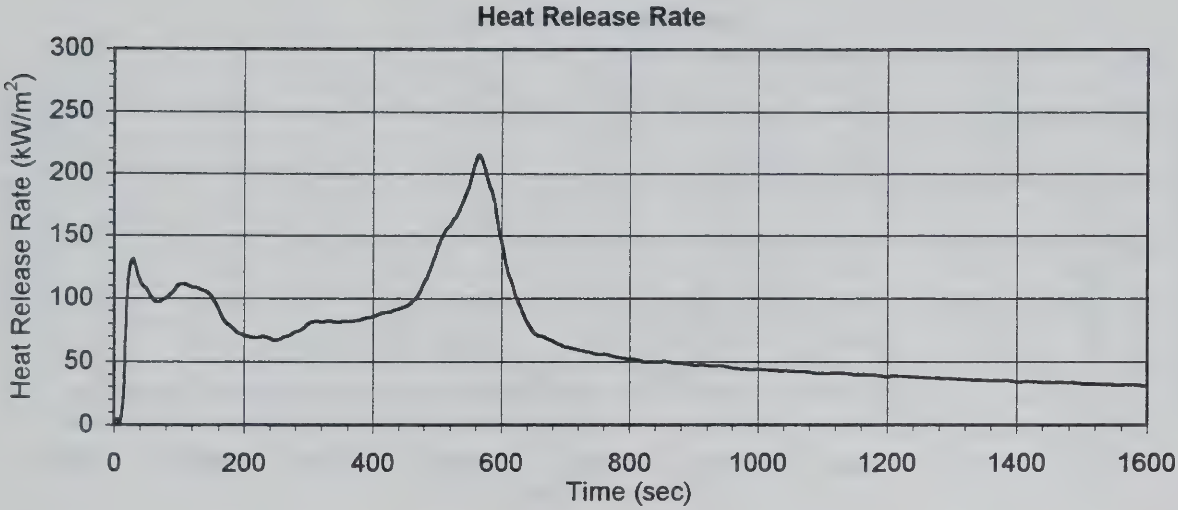
40 kW/m^2, Test #1

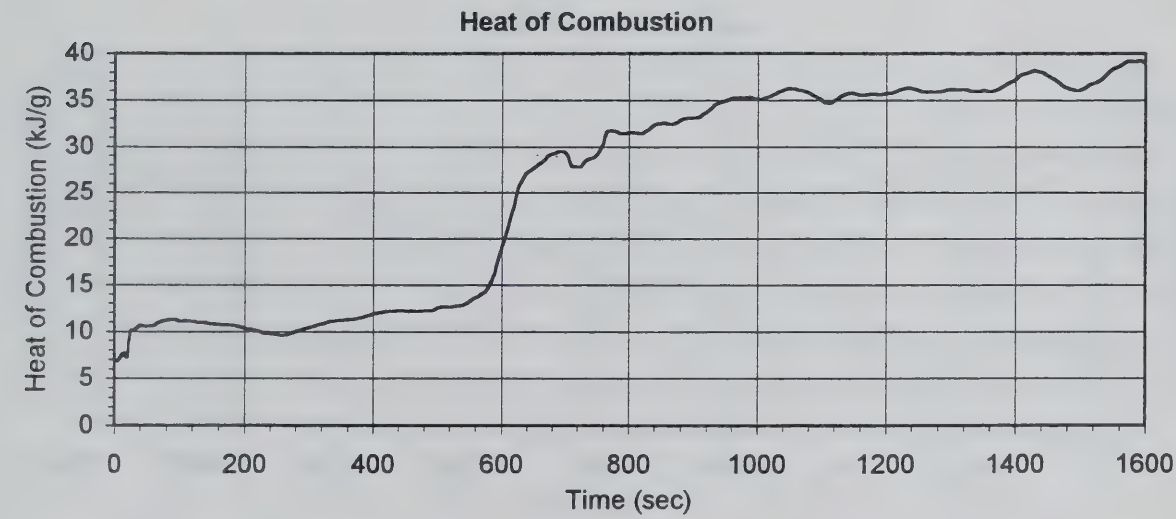


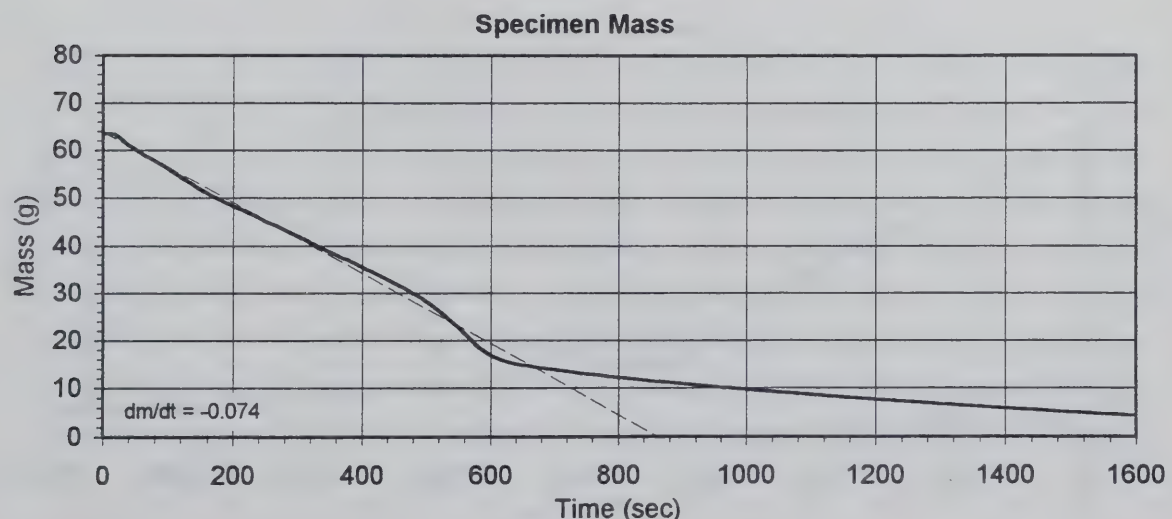




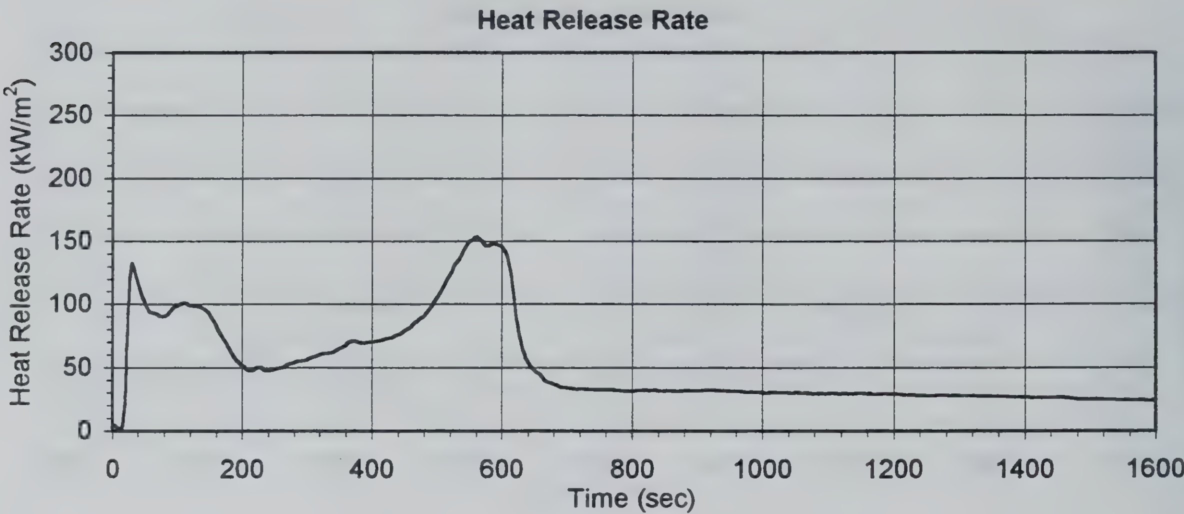
Cone Calorimeter Data R 4.11 Normal Plywood
40 kW/m^2, Test #2

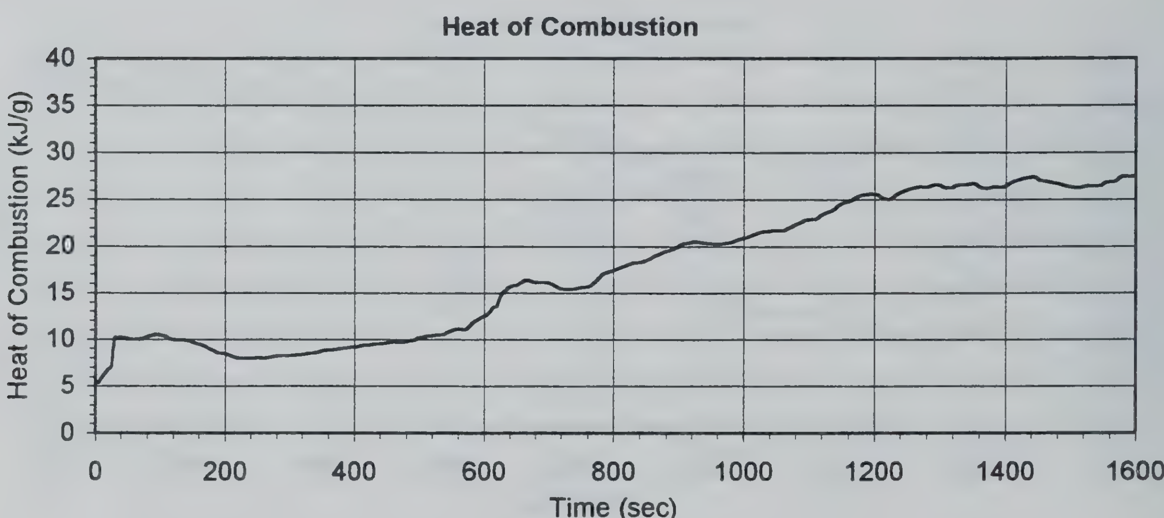


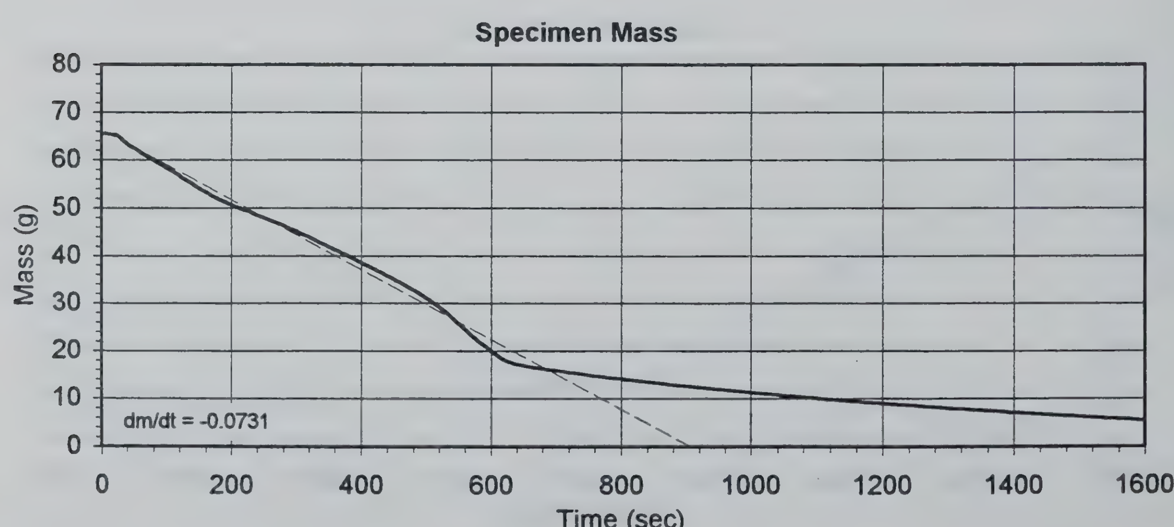




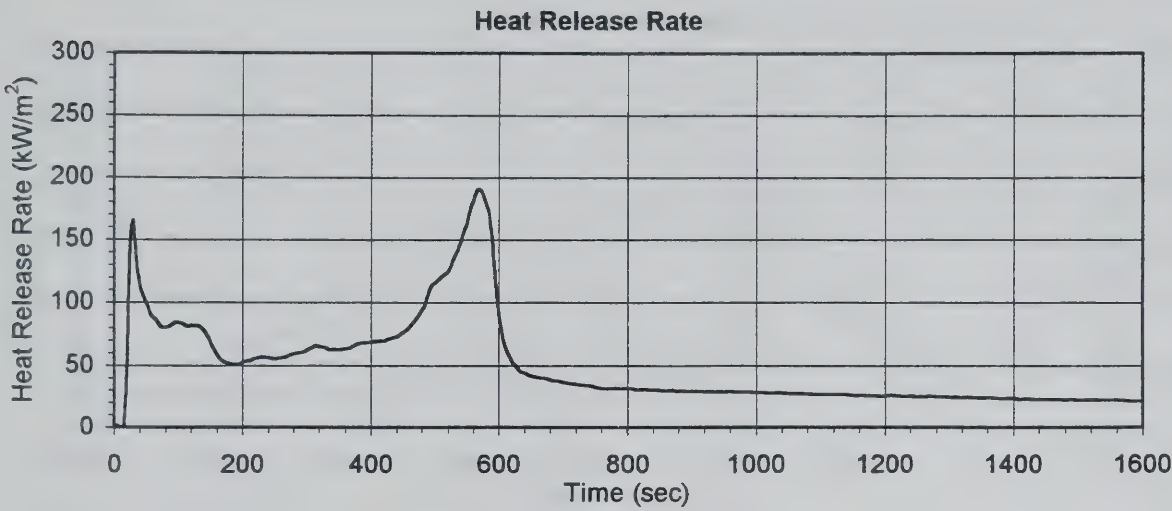
Cone Calorimeter Data R 4.11 Normal Plywood
40 kW/m^2, Test #3

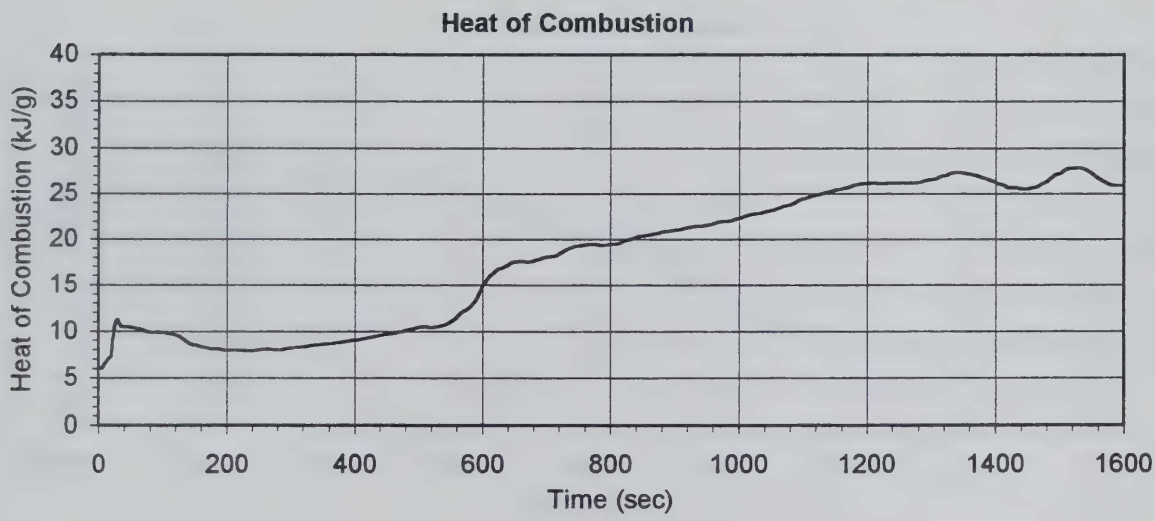


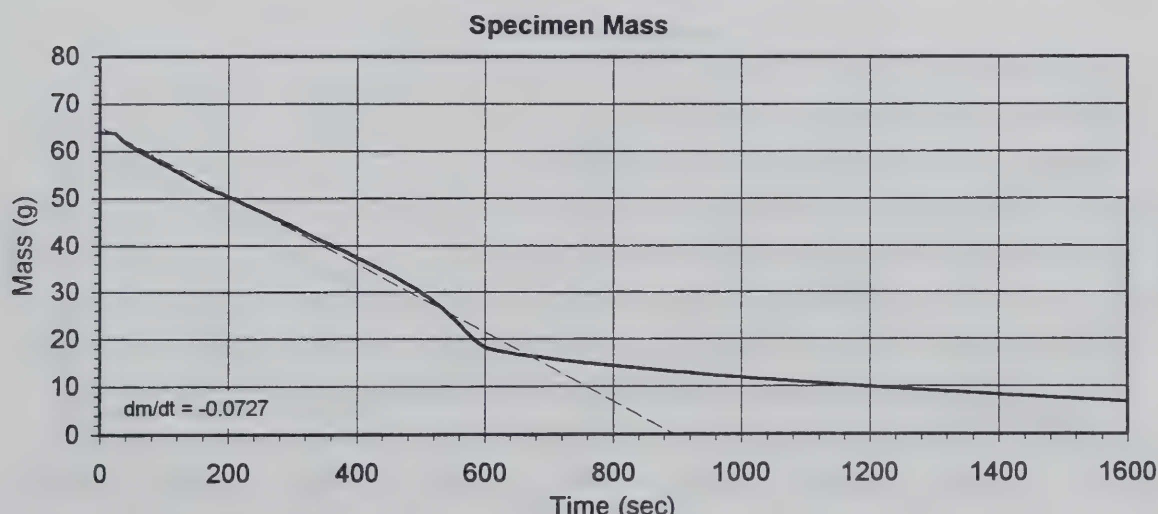




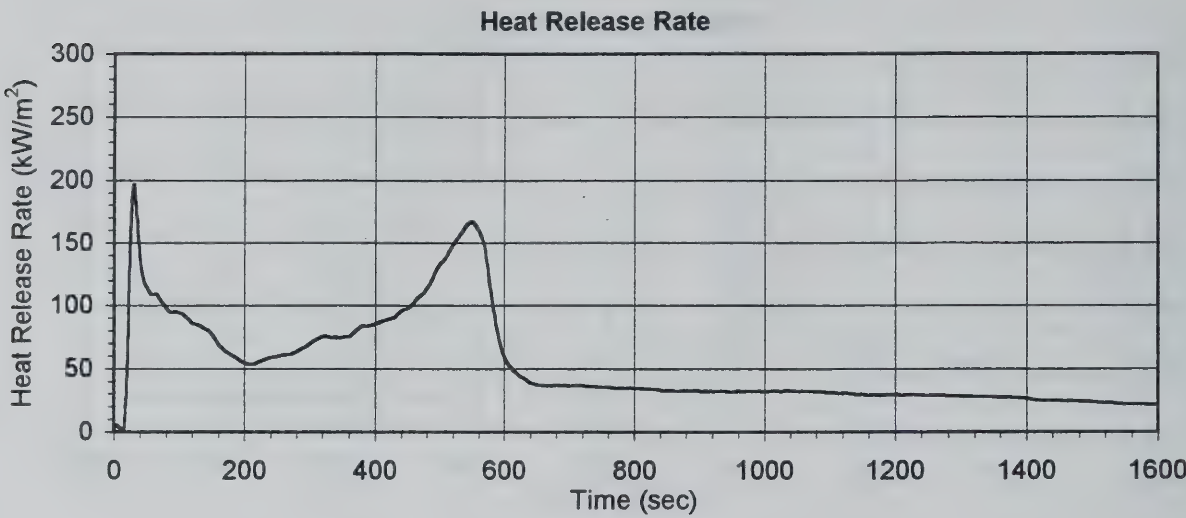
Cone Calorimeter Data R 4.11 Normal Plywood
40 kW/m^2, Test #4

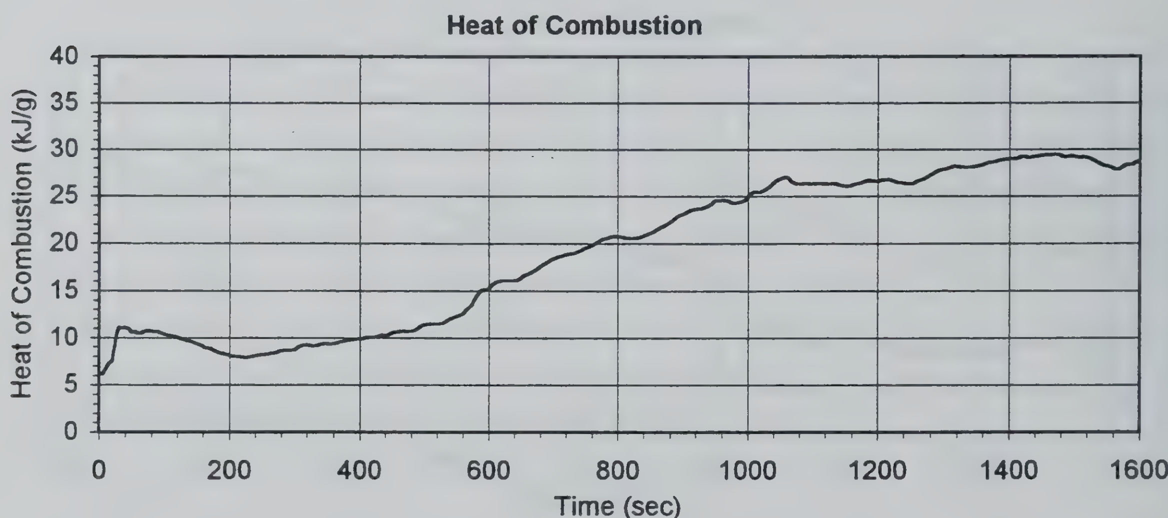


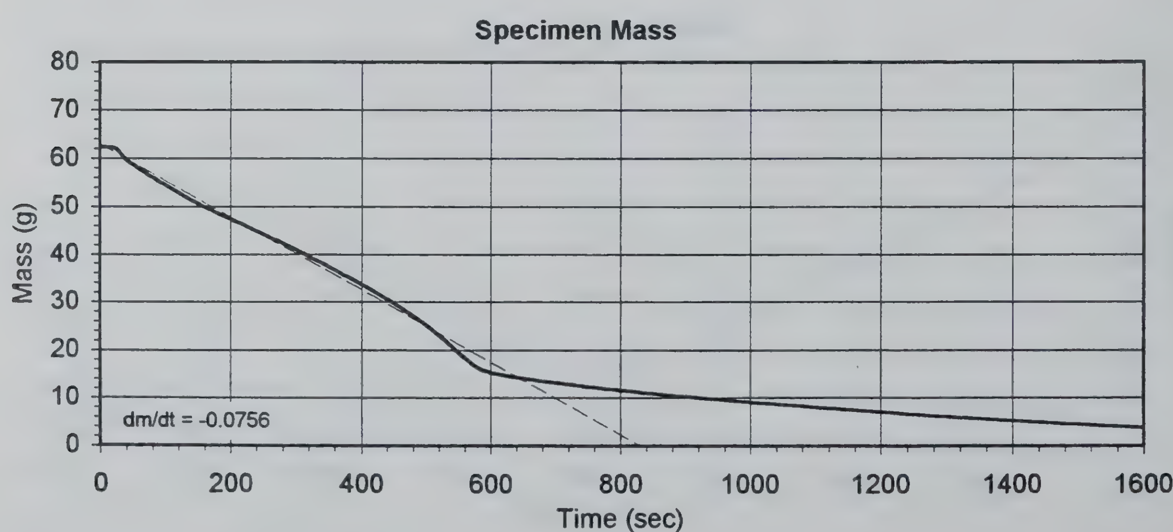




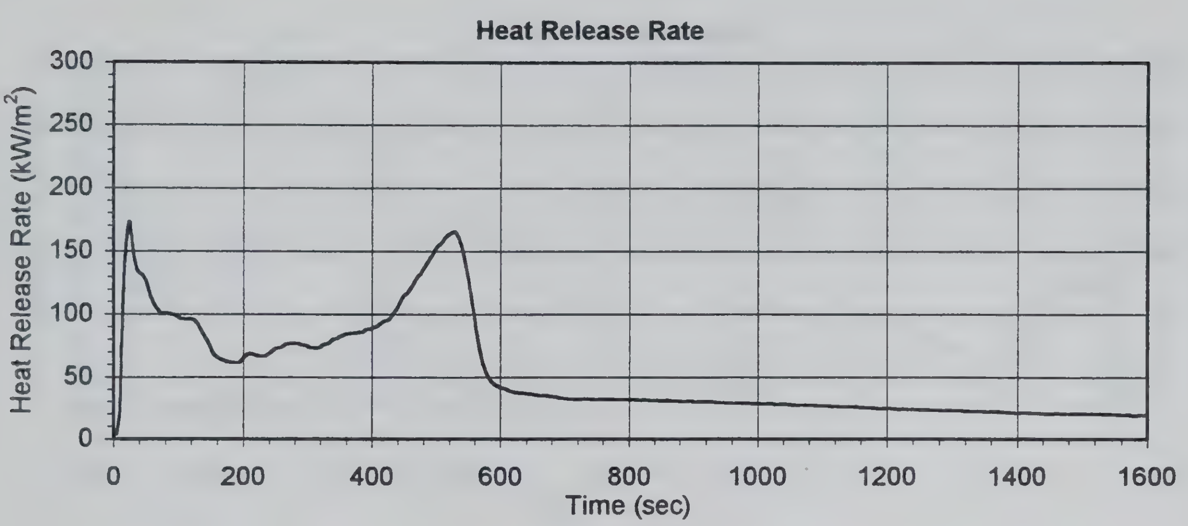
Cone Calorimeter Data R 4.11 Normal Plywood
40 kW/m^2, Test #5

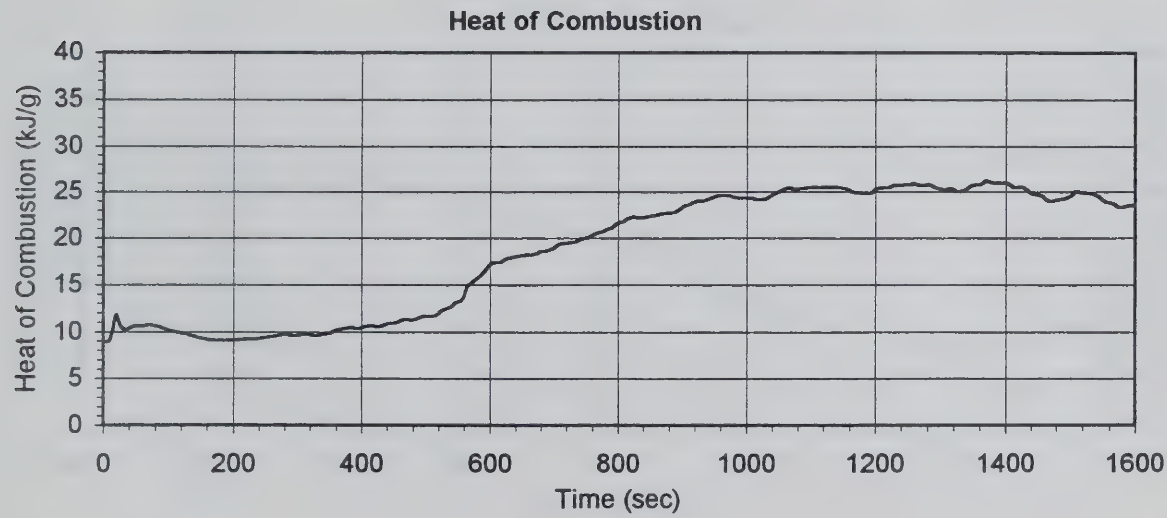


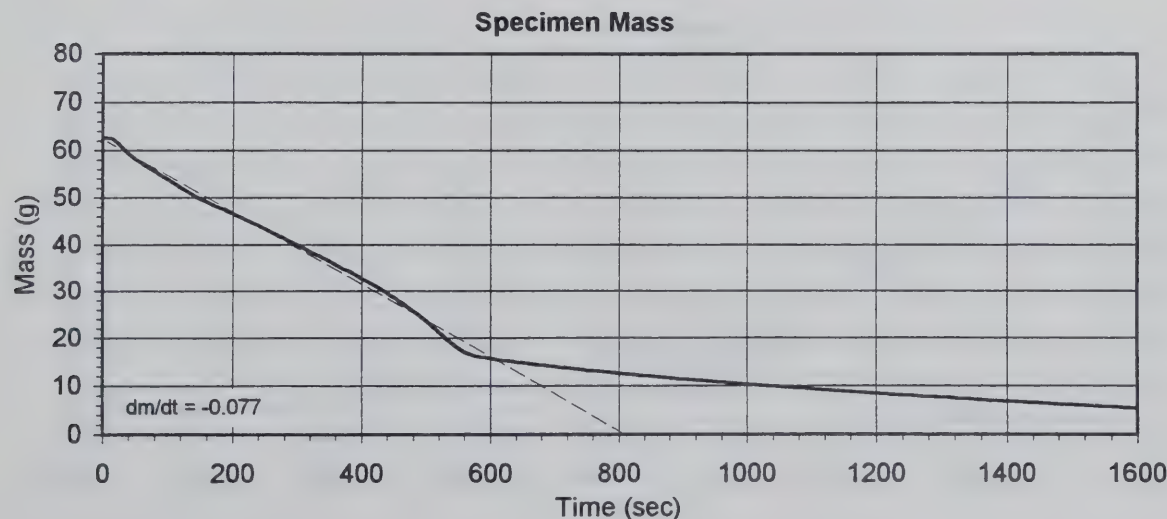




Cone Calorimeter Data R 4.11 Normal Plywood
50 kW/m^2, Test #1

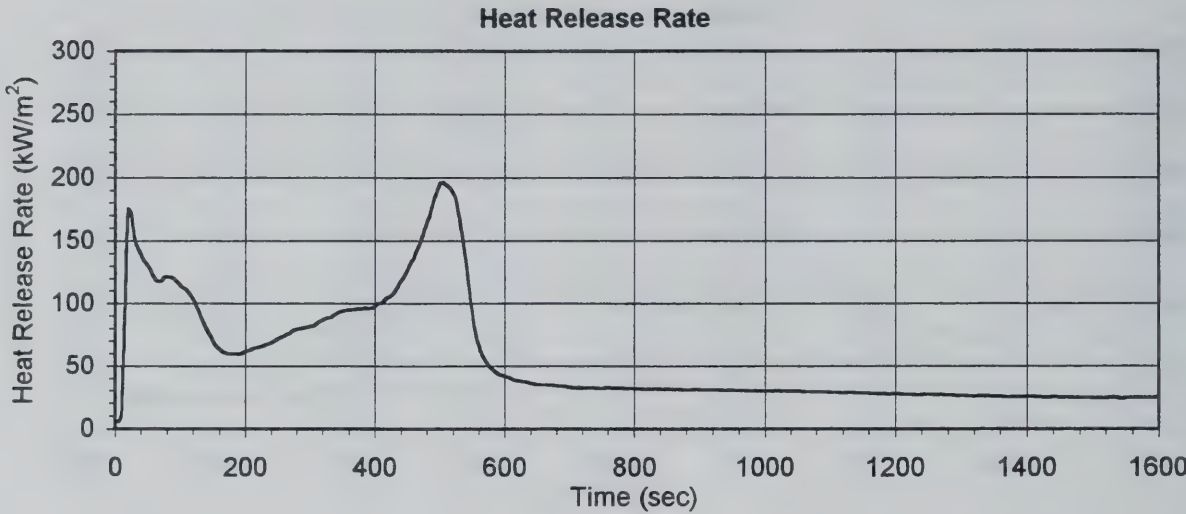


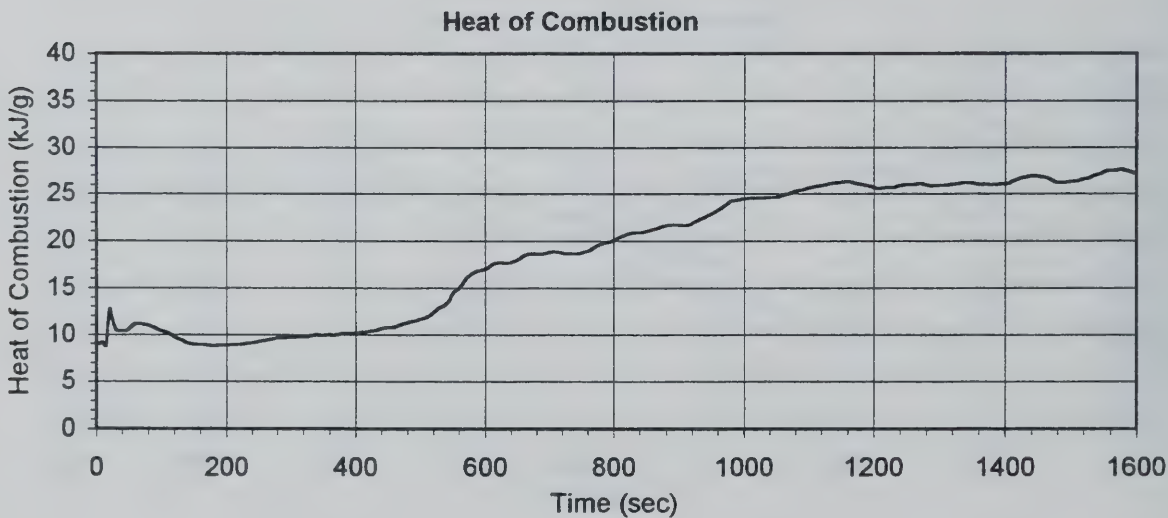


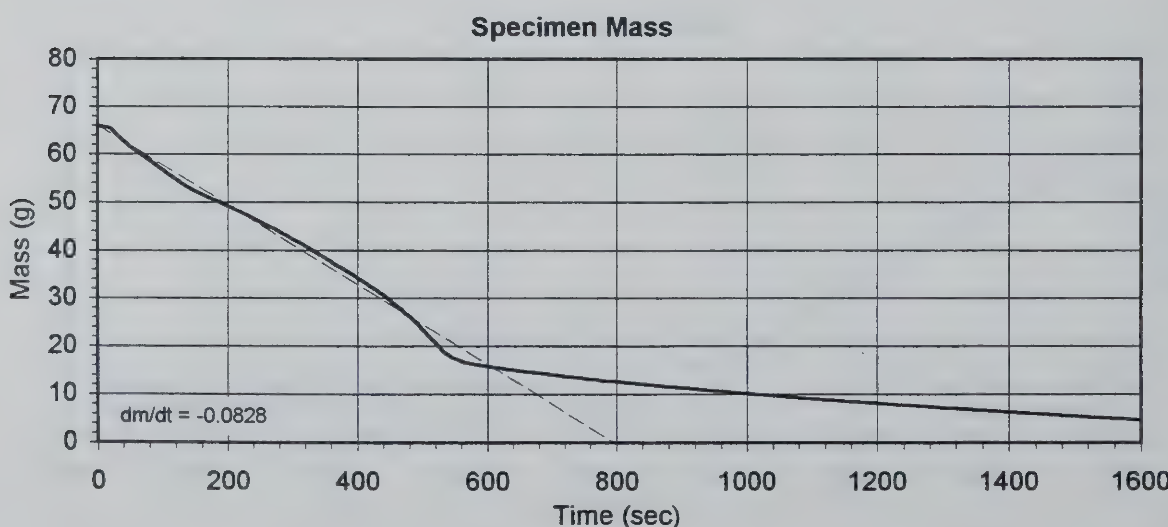


Cone Calorimeter Data R 4.11 Normal Plywood

50 kW/m^2, Test #2

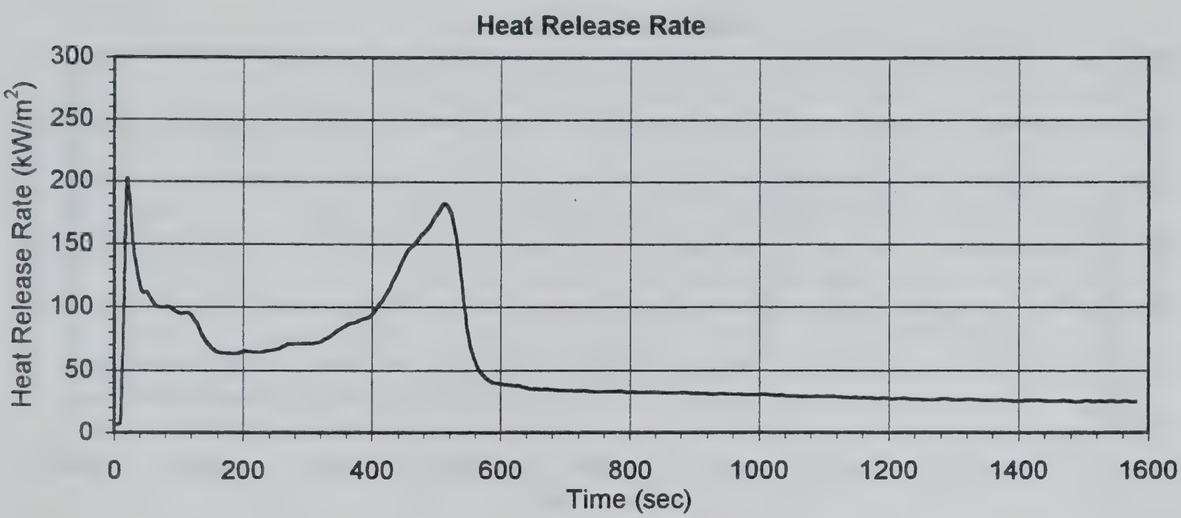


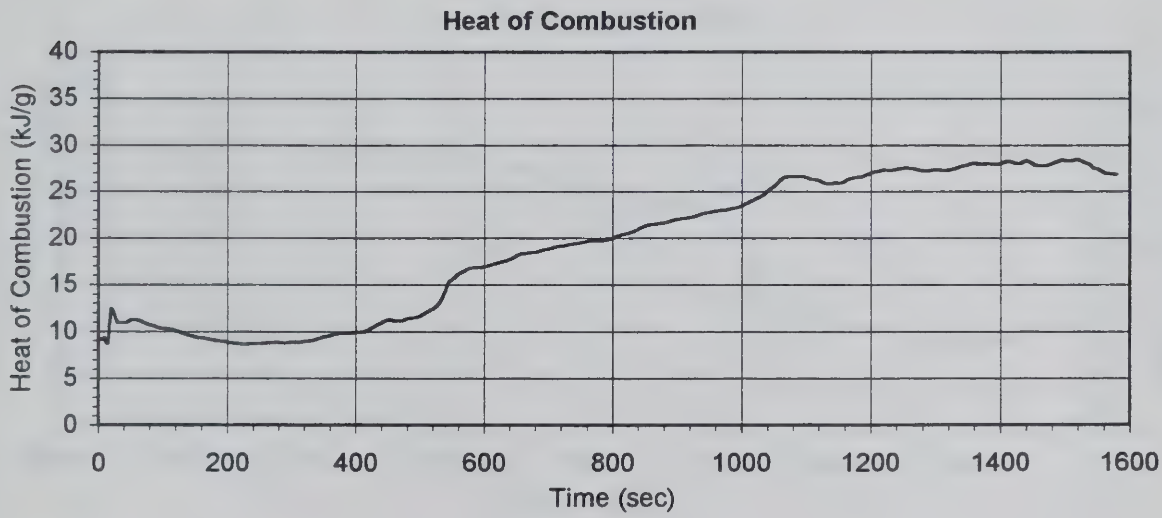


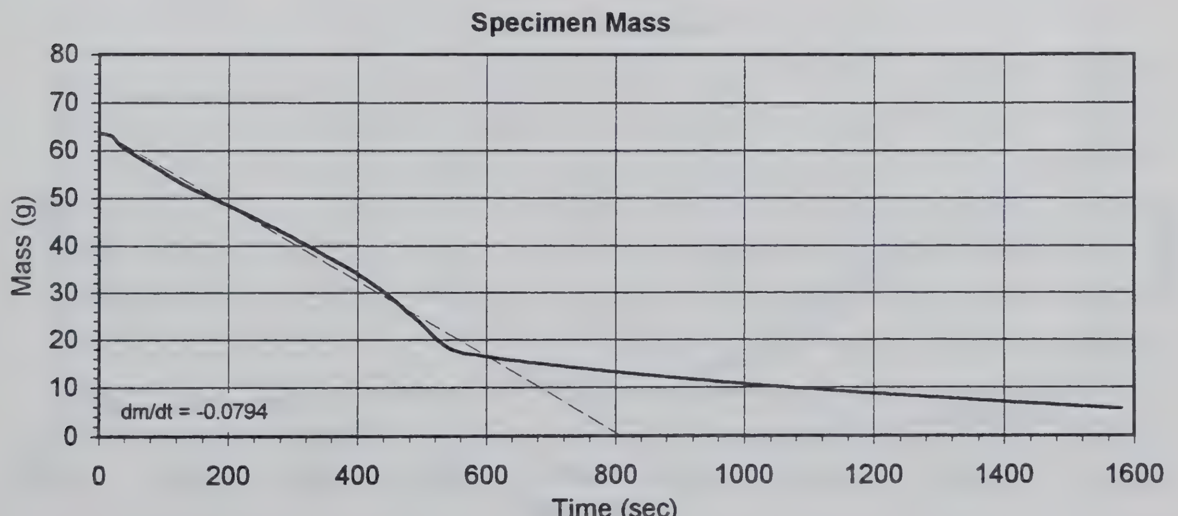


Cone Calorimeter Data R 4.11 Normal Plywood

50 kW/m^2, Test #3

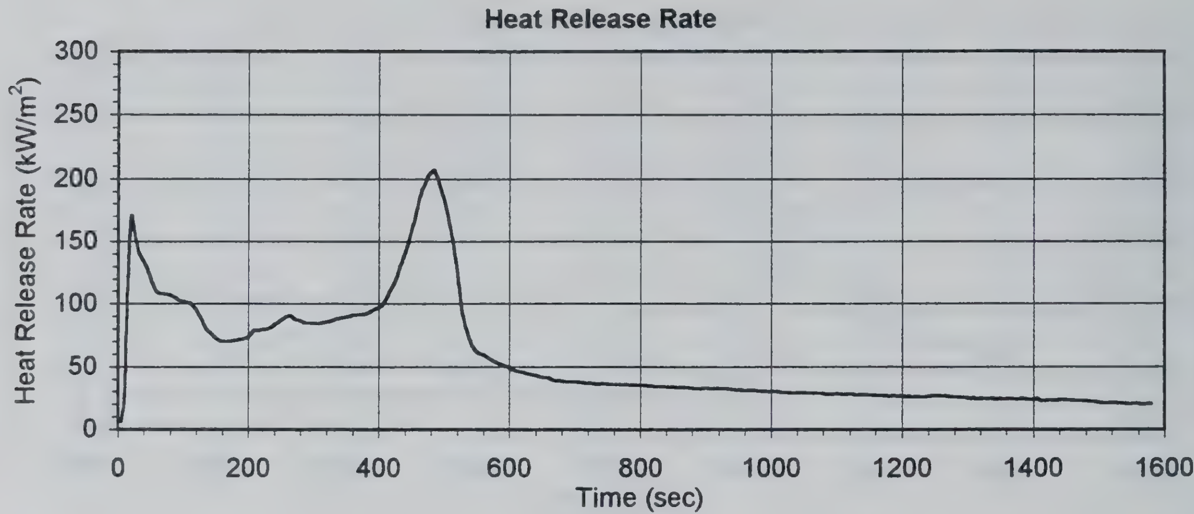


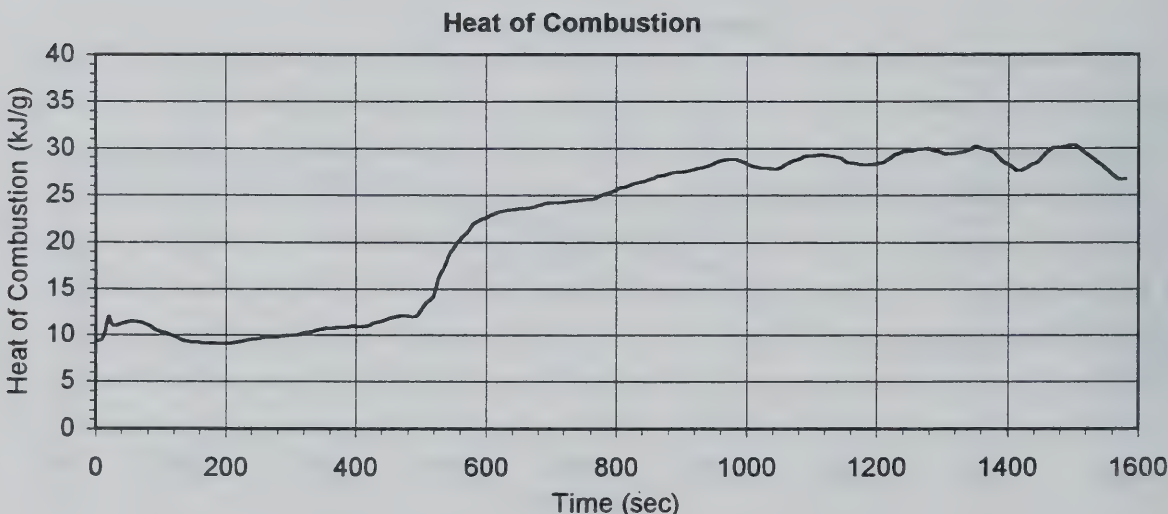


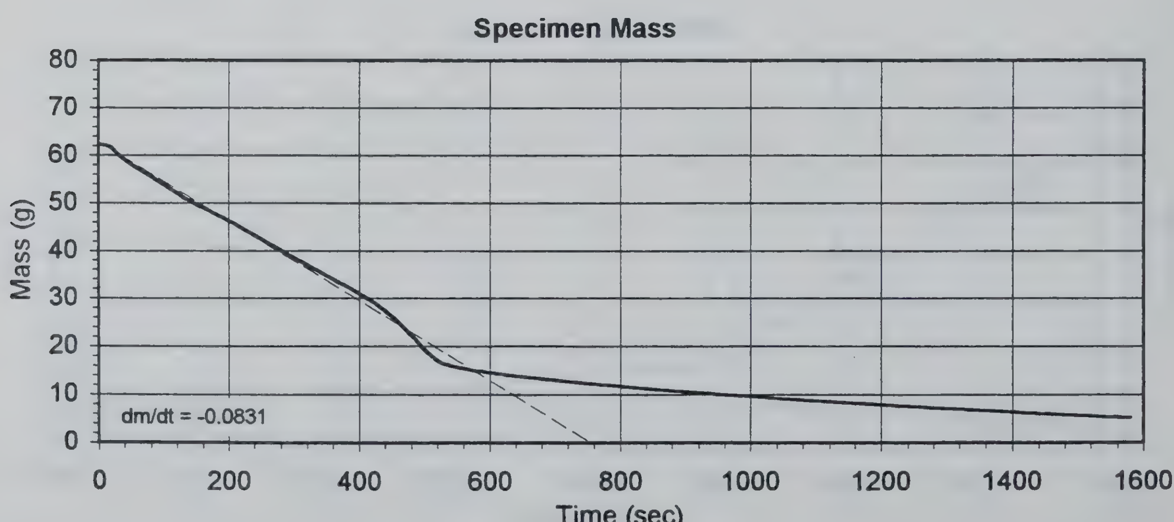


Cone Calorimeter Data R 4.11 Normal Plywood

50 kW/m^2, Test #4

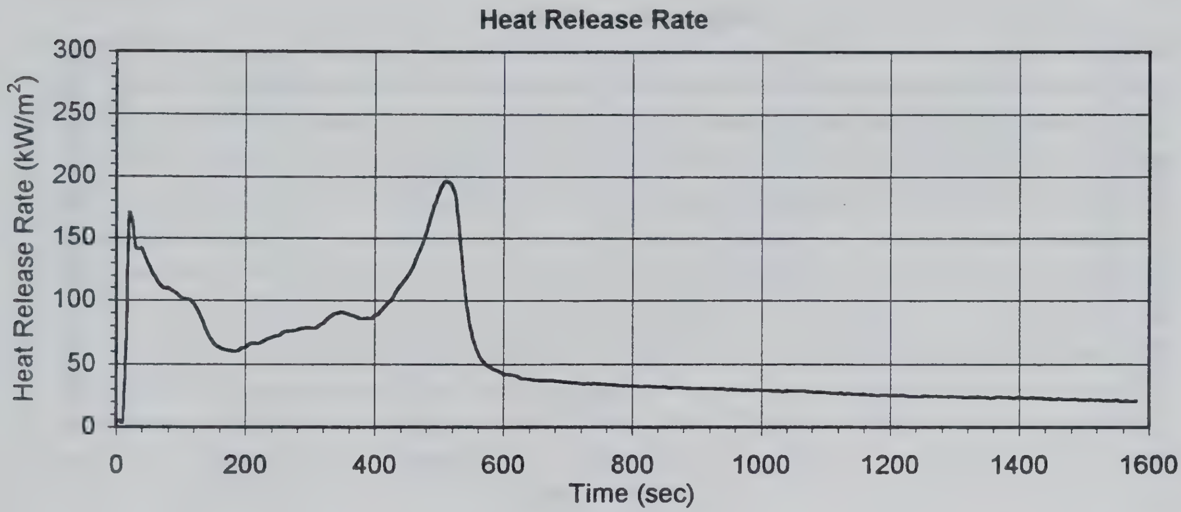


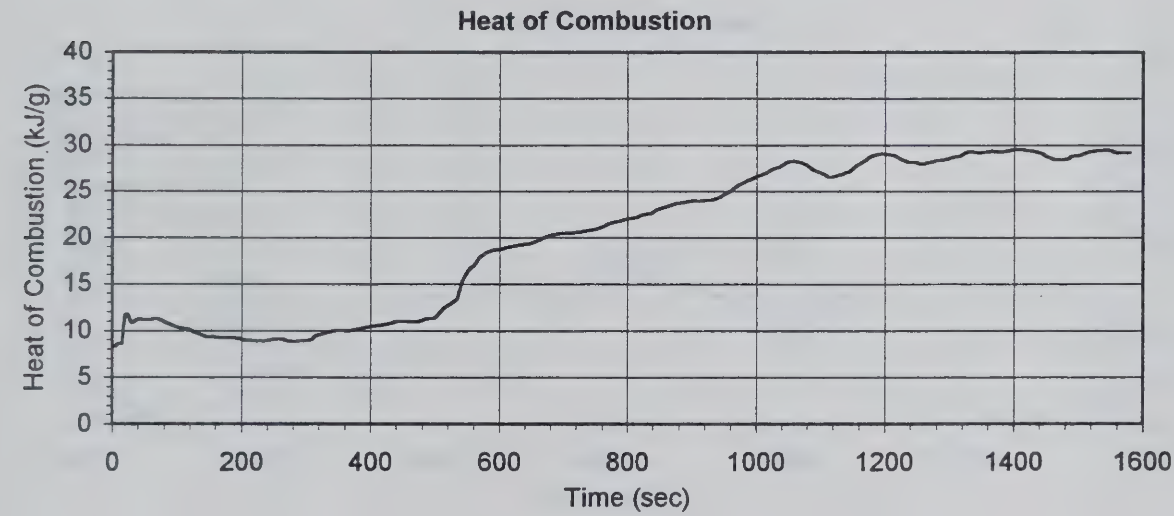


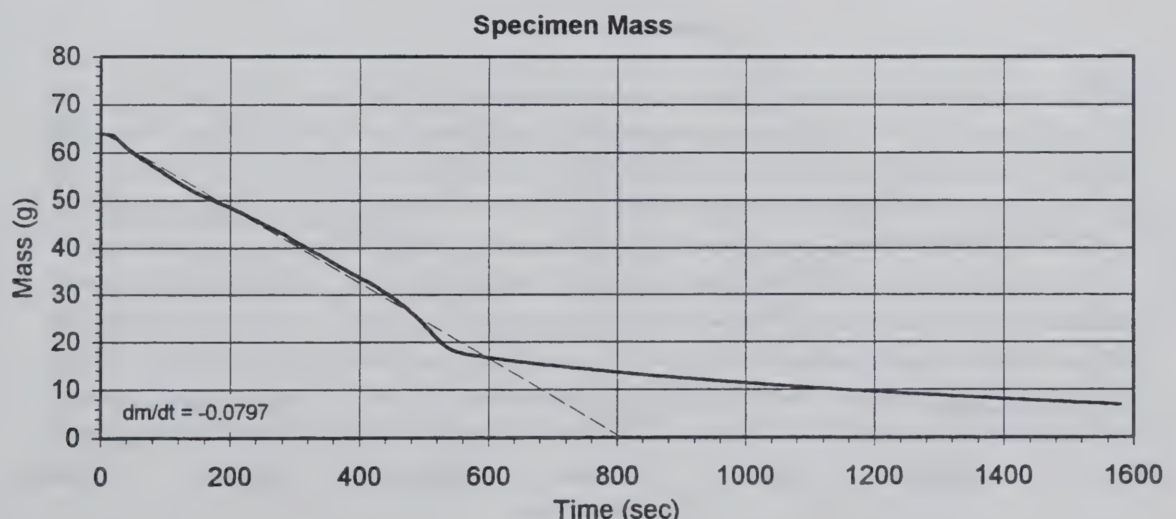


Cone Calorimeter Data R 4.11 Normal Plywood

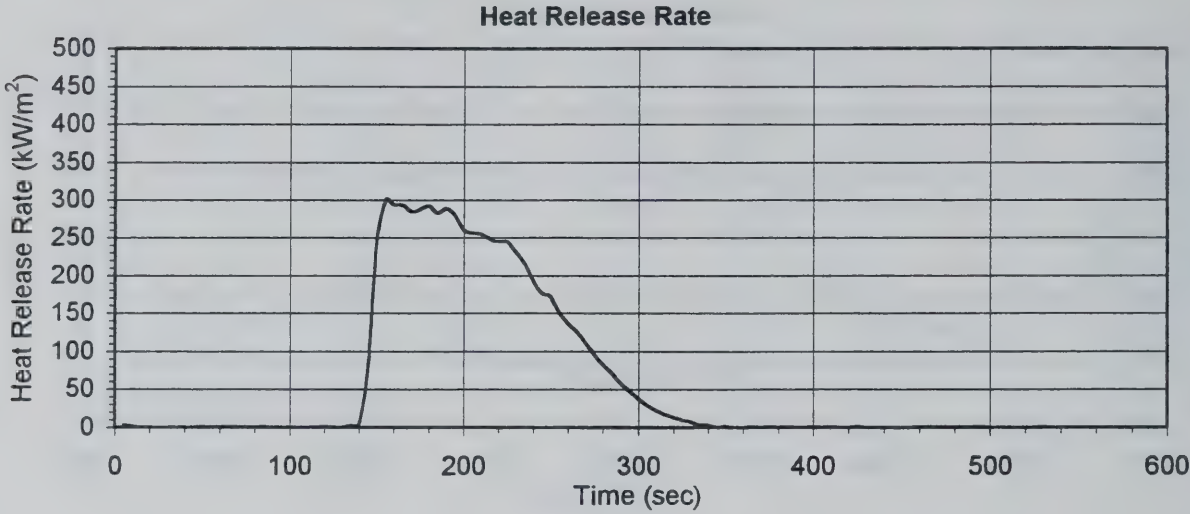
50 kW/m^2, Test #5

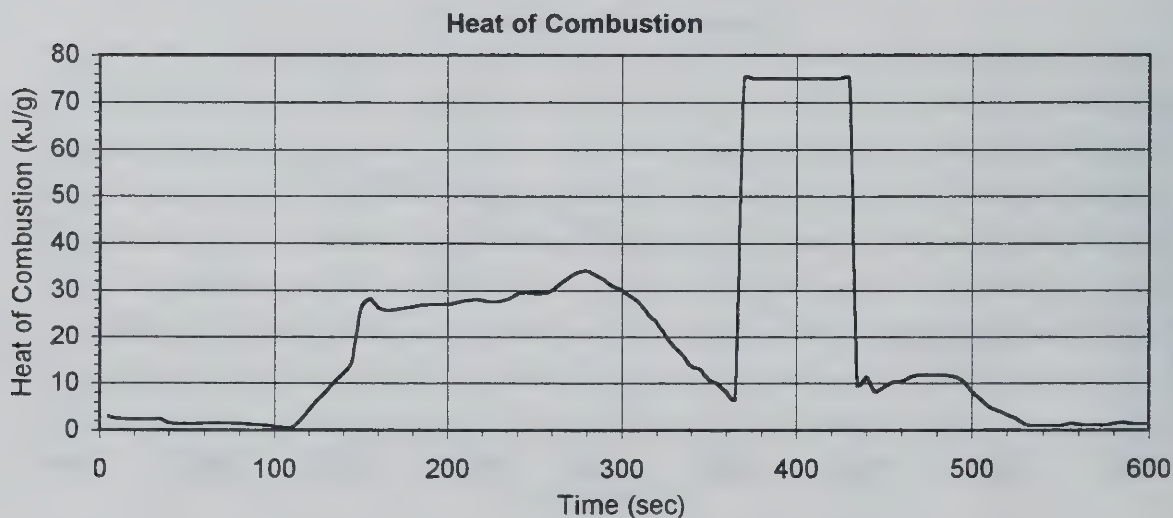


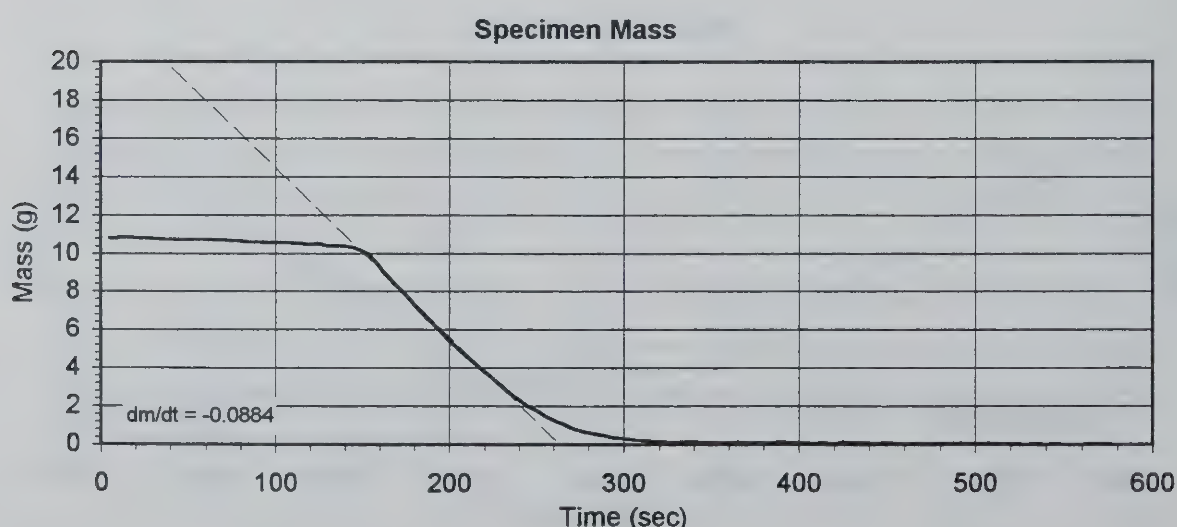




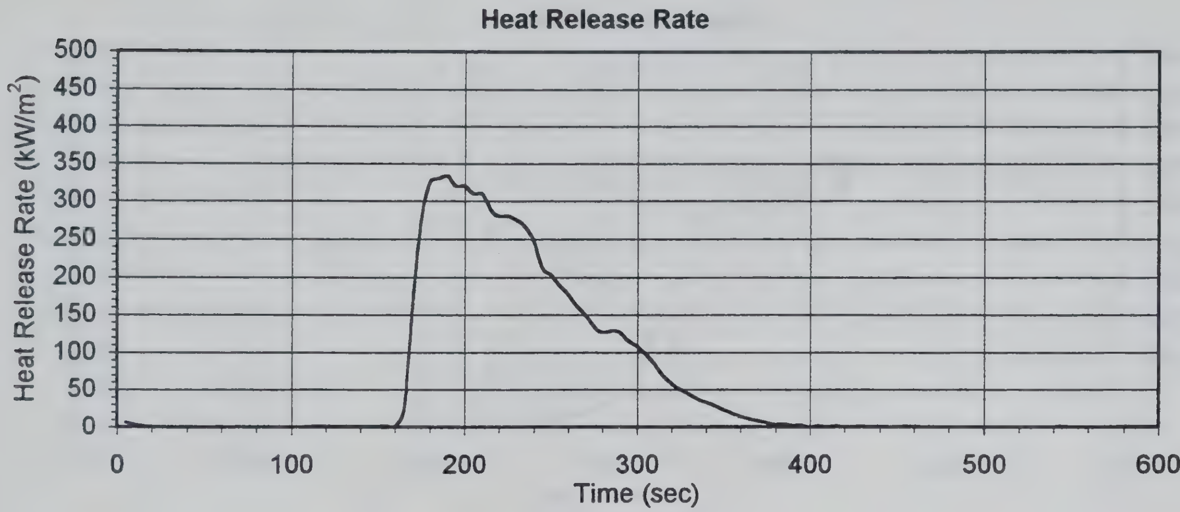
Cone Calorimeter Data R 4.20 F.R. Expanded Polystyrene Board (40 mm)
25 kW/m^2, Test #1

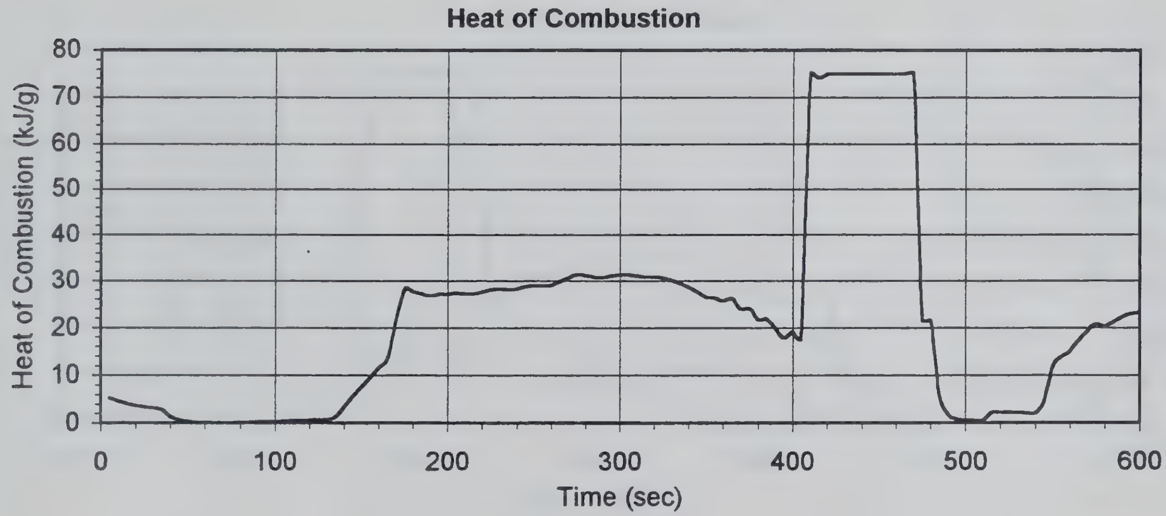


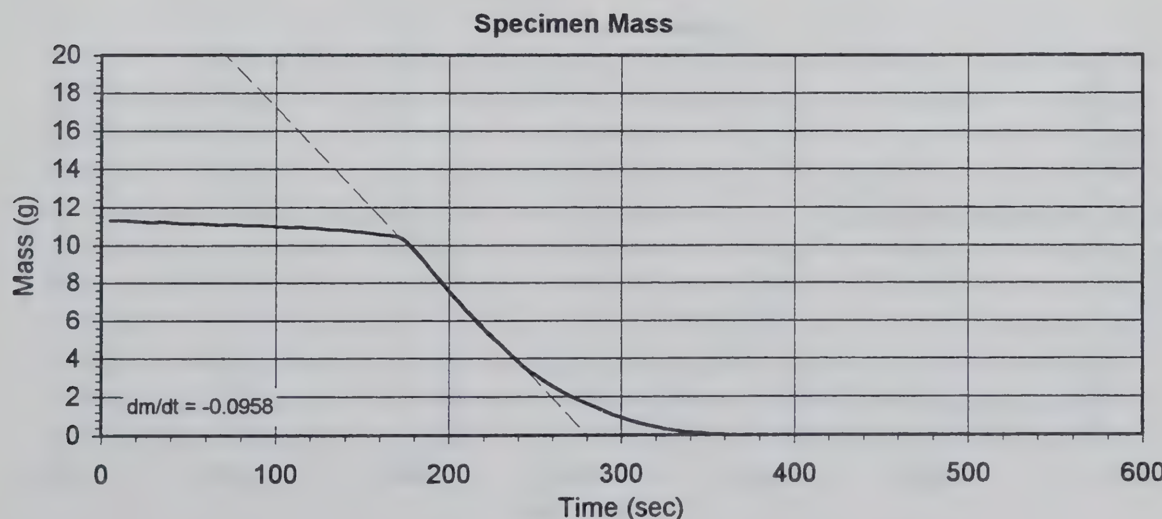




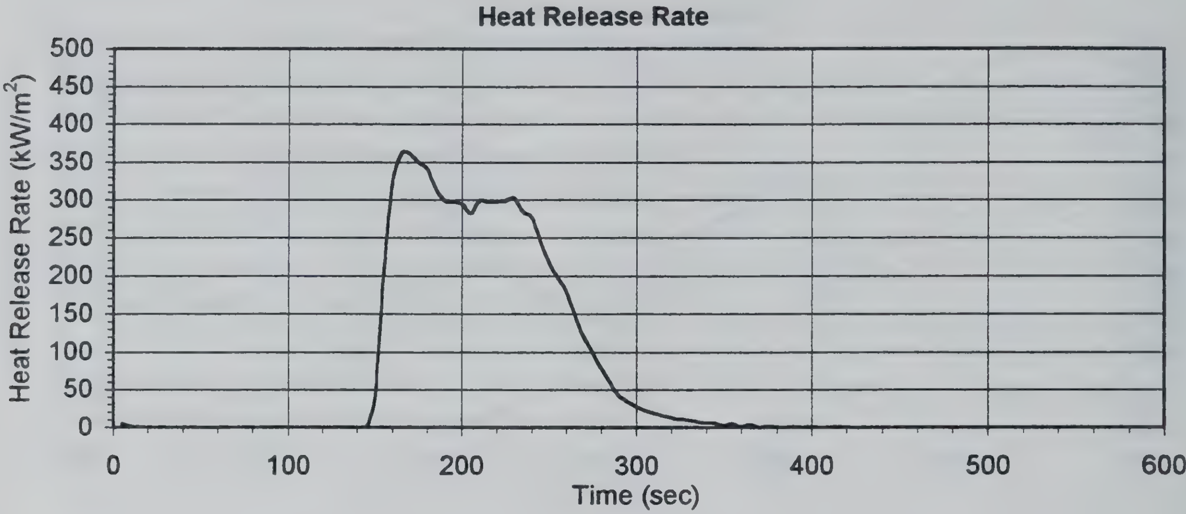
Cone Calorimeter Data R 4.20 F.R. Expanded Polystyrene Board (40 mm)
25 kW/m^2, Test #2

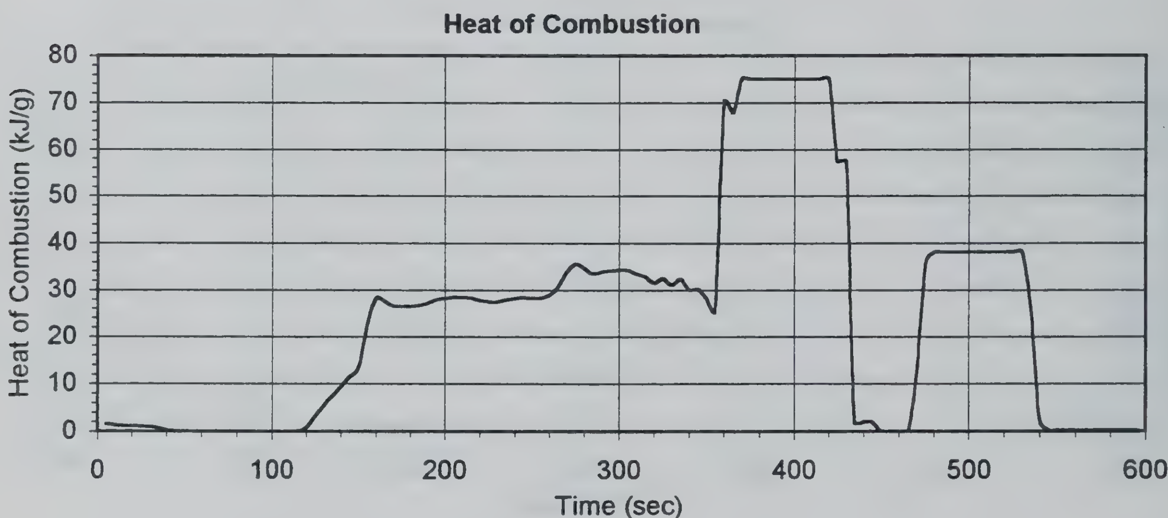


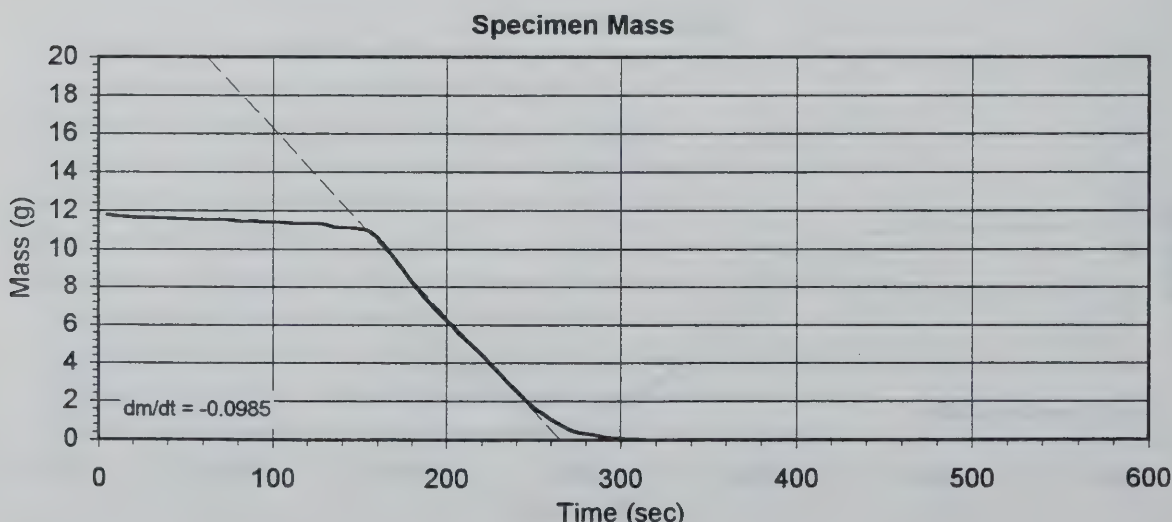




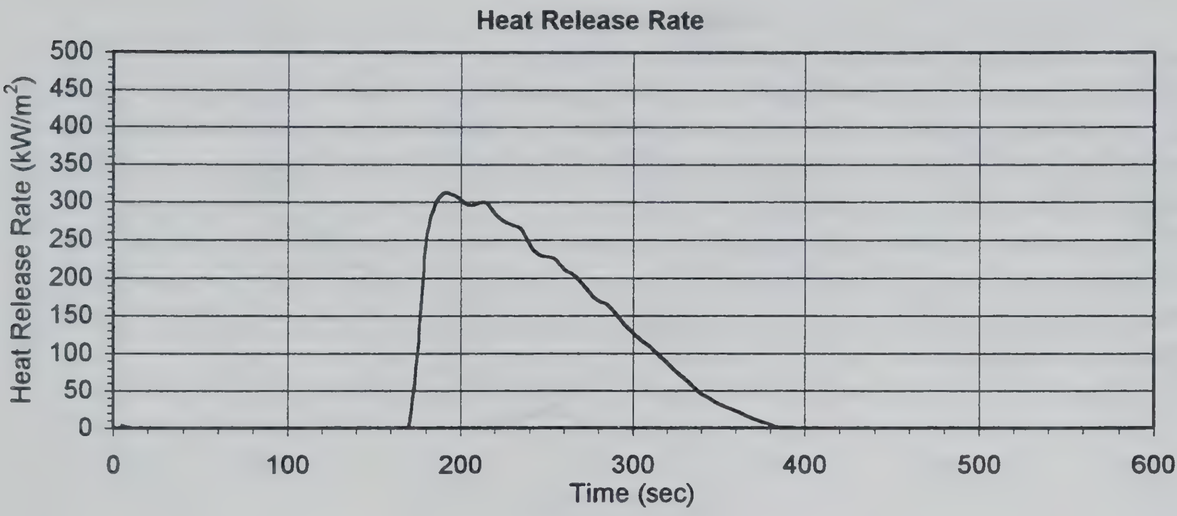
Cone Calorimeter Data R 4.20 F.R. Expanded Polystyrene Board (40 mm)
25 kW/m^2, Test #3

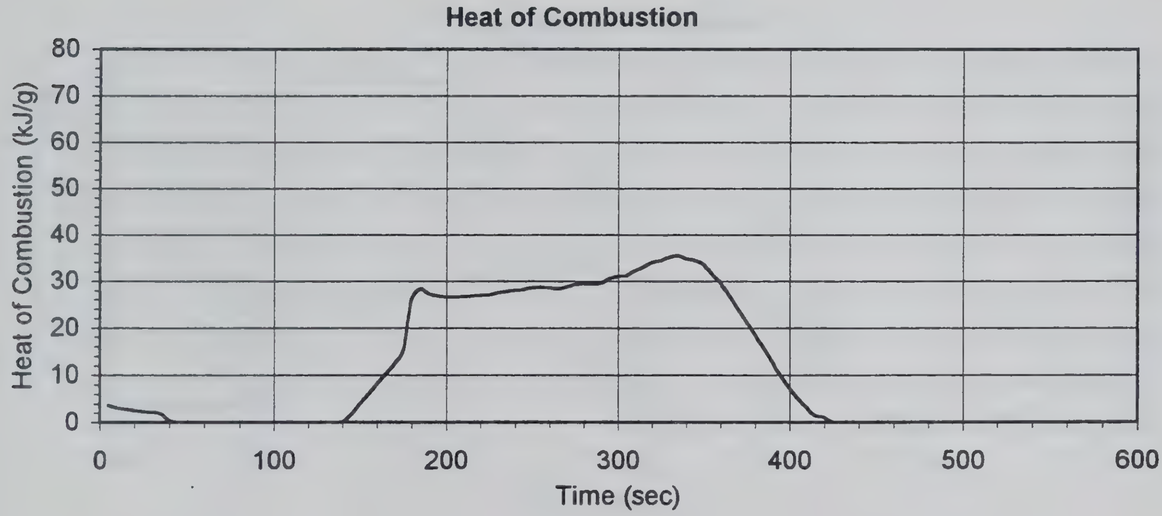


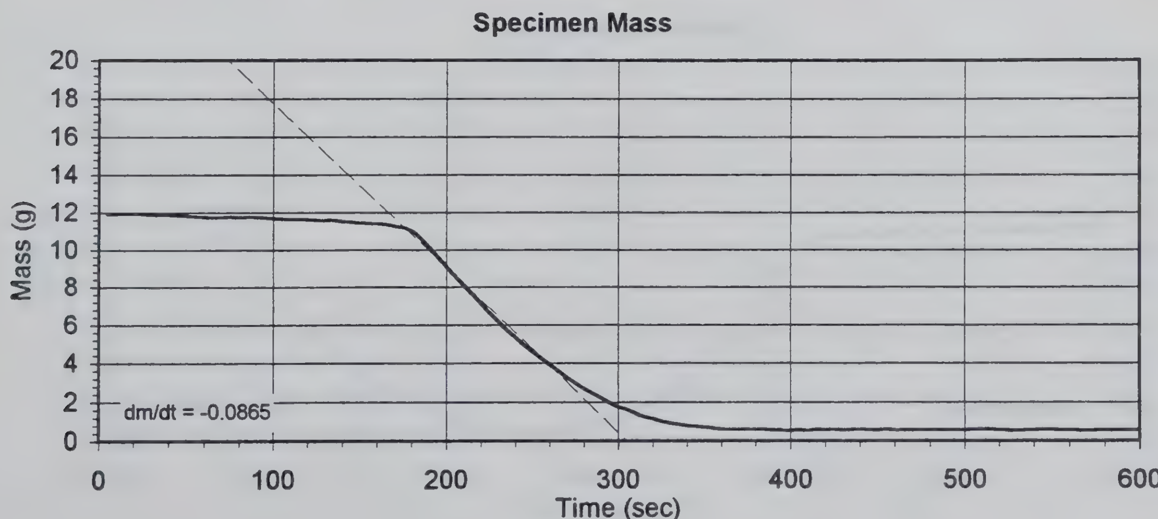




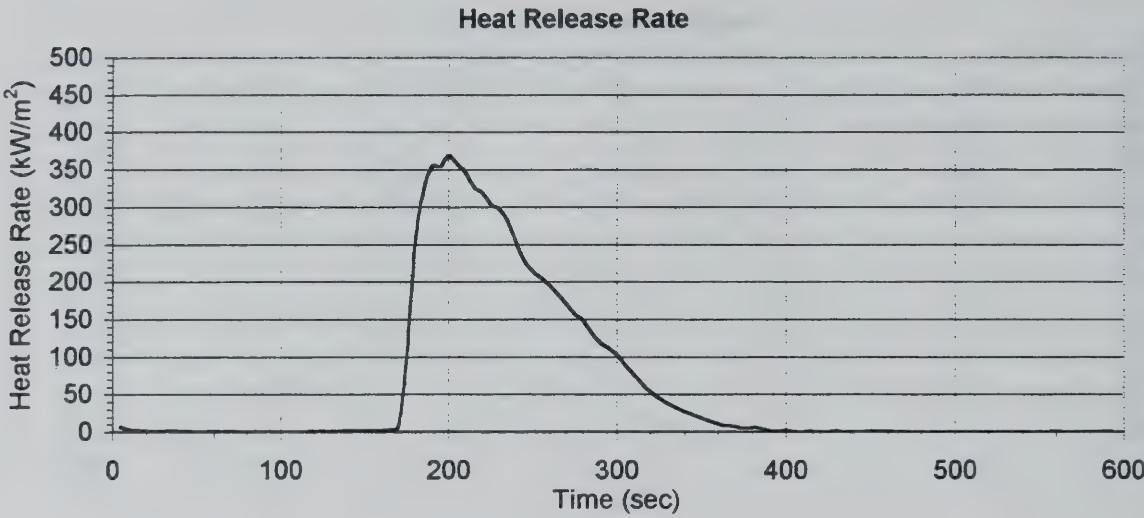
Cone Calorimeter Data R 4.20 F.R. Expanded Polystyrene Board (40 mm)
25 kW/m^2, Test #4

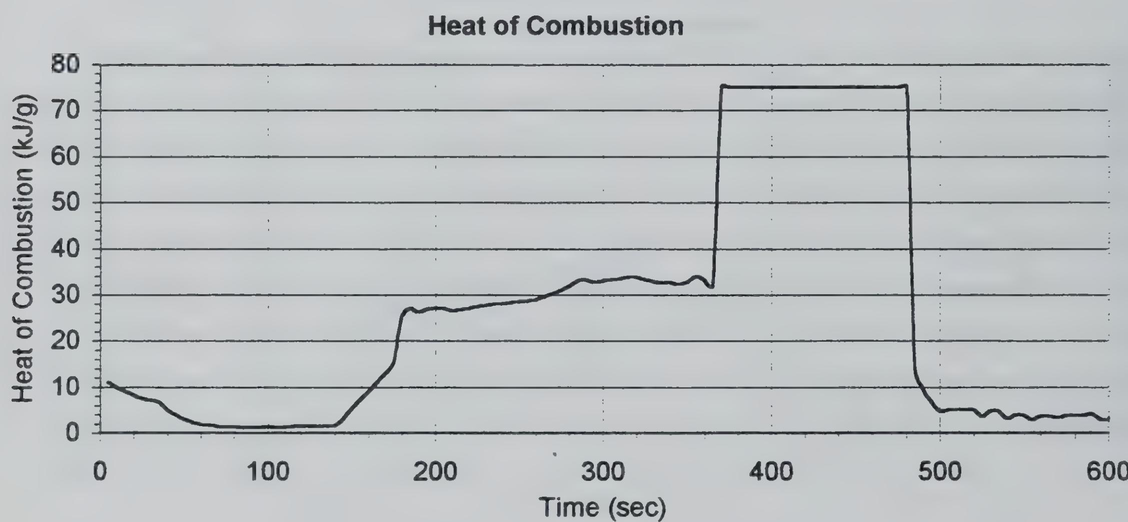


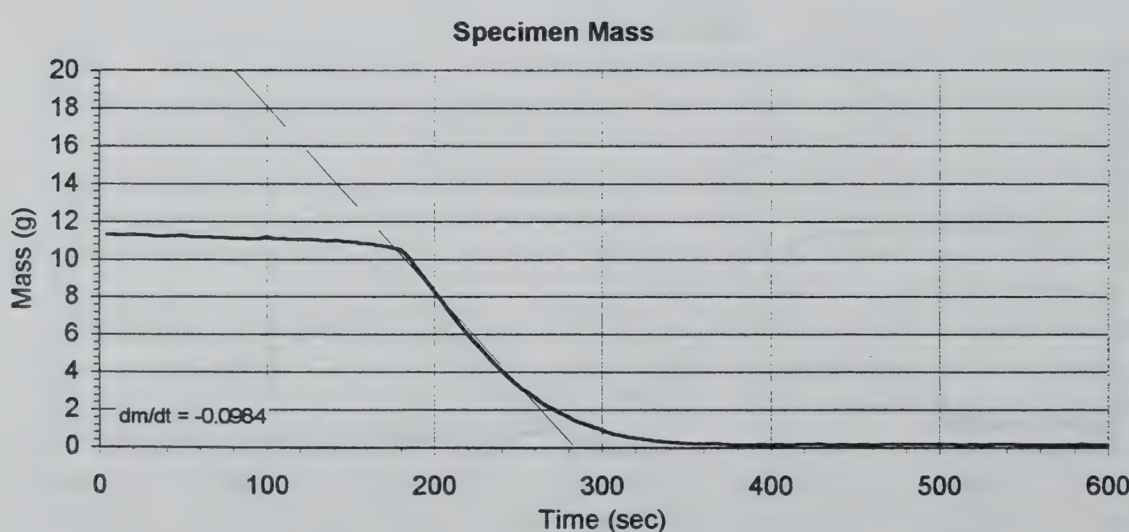




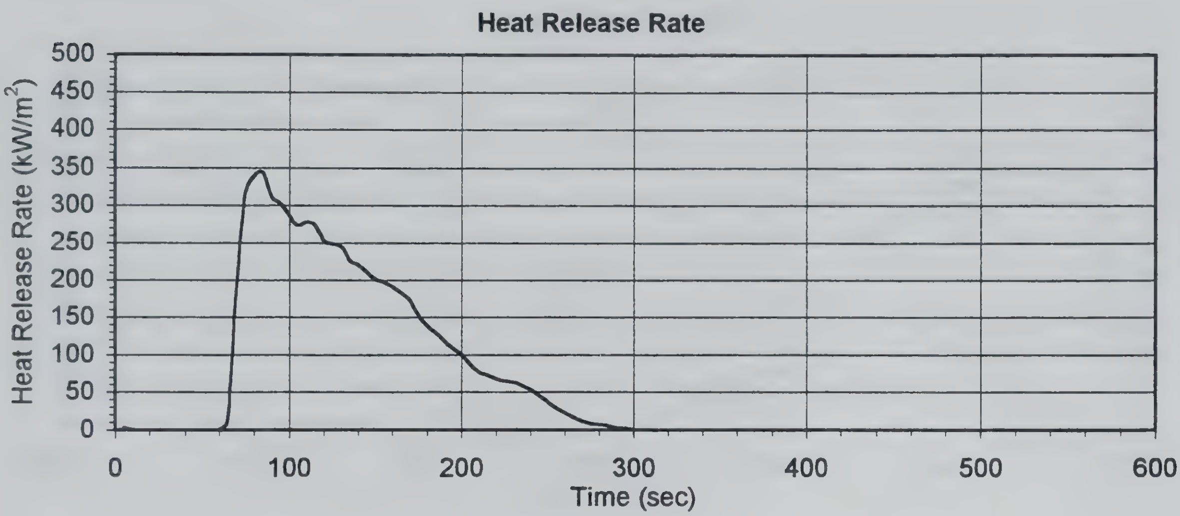
Cone Calorimeter Data R 4.20 F.R. Expanded Polystyrene Board (40 mm)
25 kW/m^2, Test #5

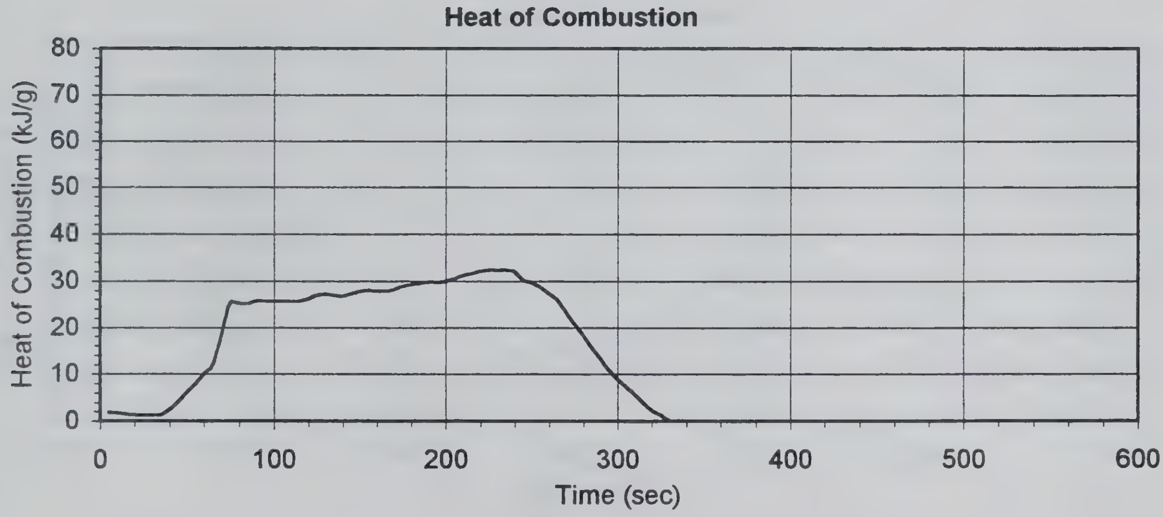


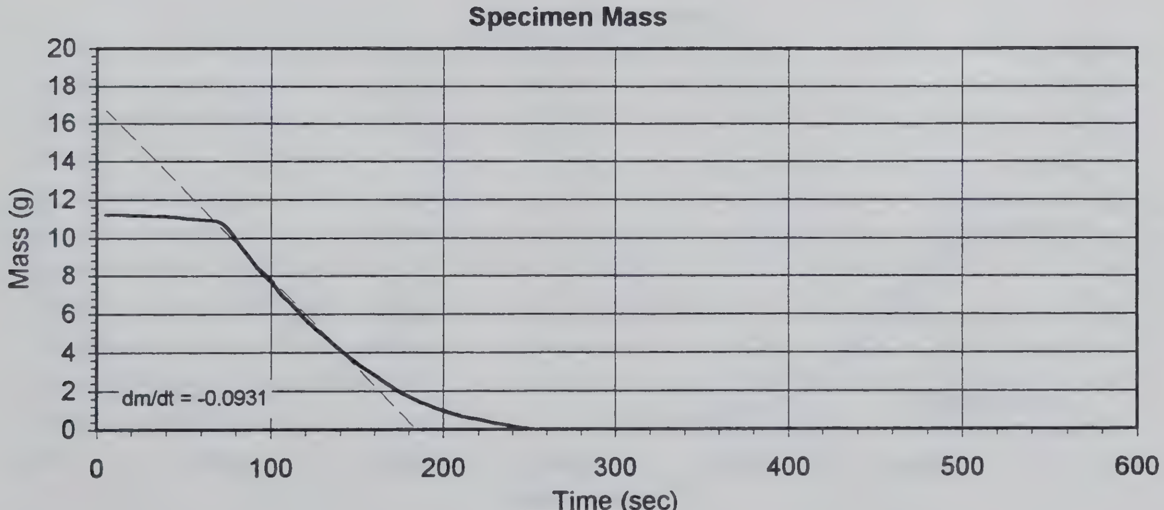




Cone Calorimeter Data R 4.20 F.R. Expanded Polystyrene Board (40 mm)
35 kW/m^2, Test #1







Cone Calorimeter Data R 4.20 F.R. Expanded Polystyrene Board (40 mm)
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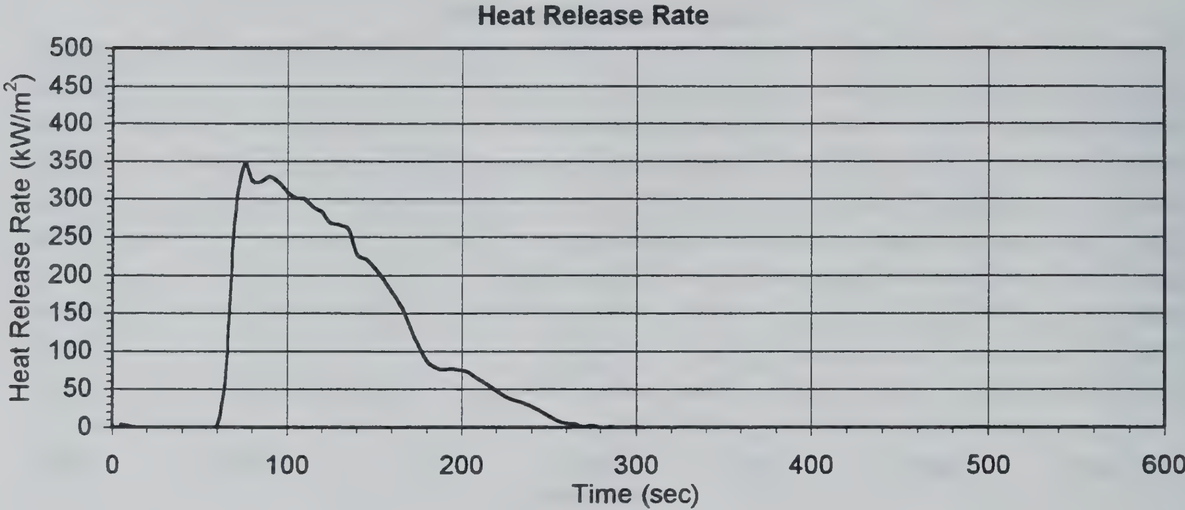
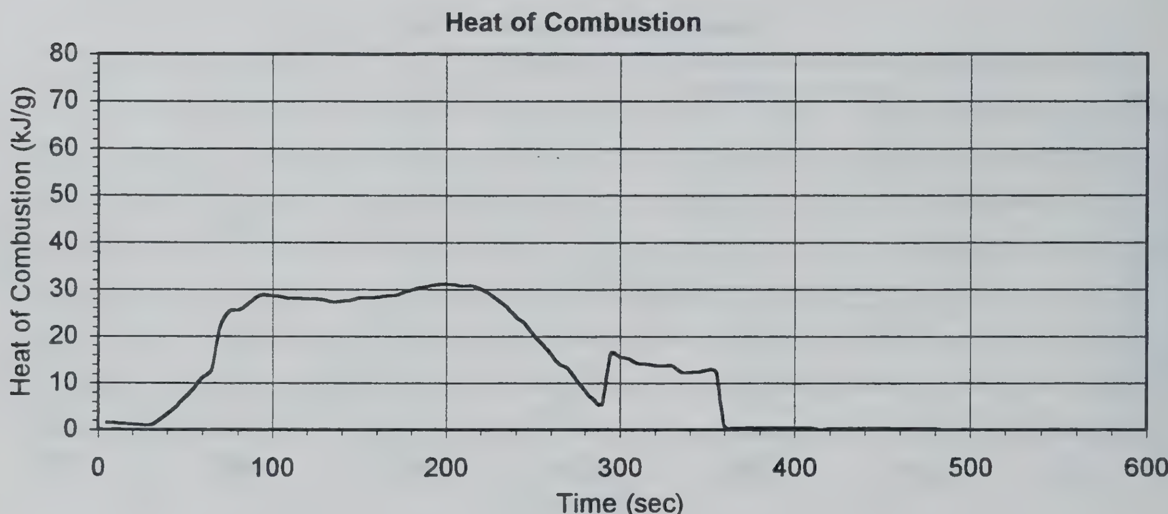
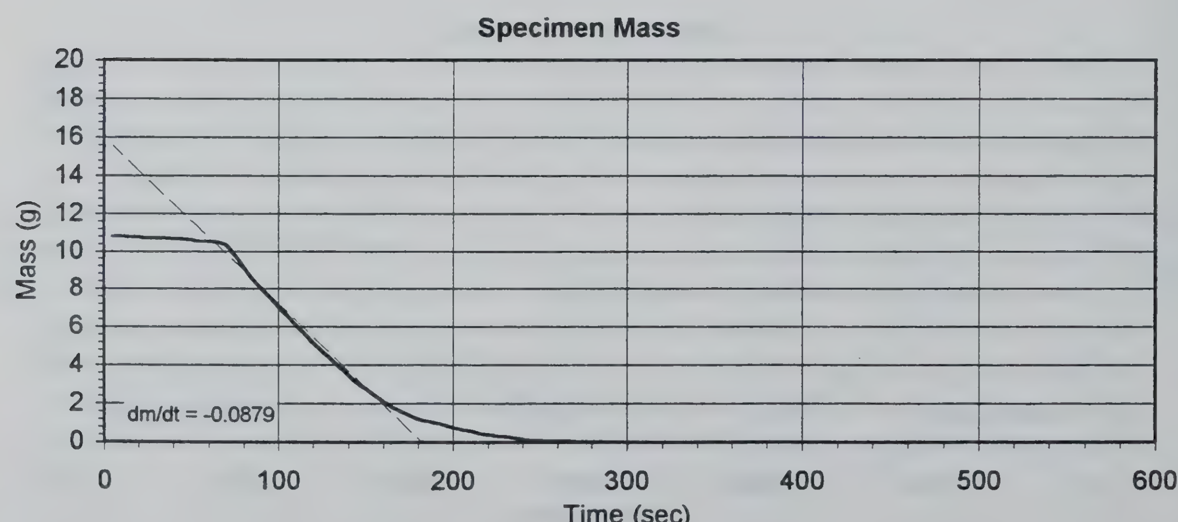
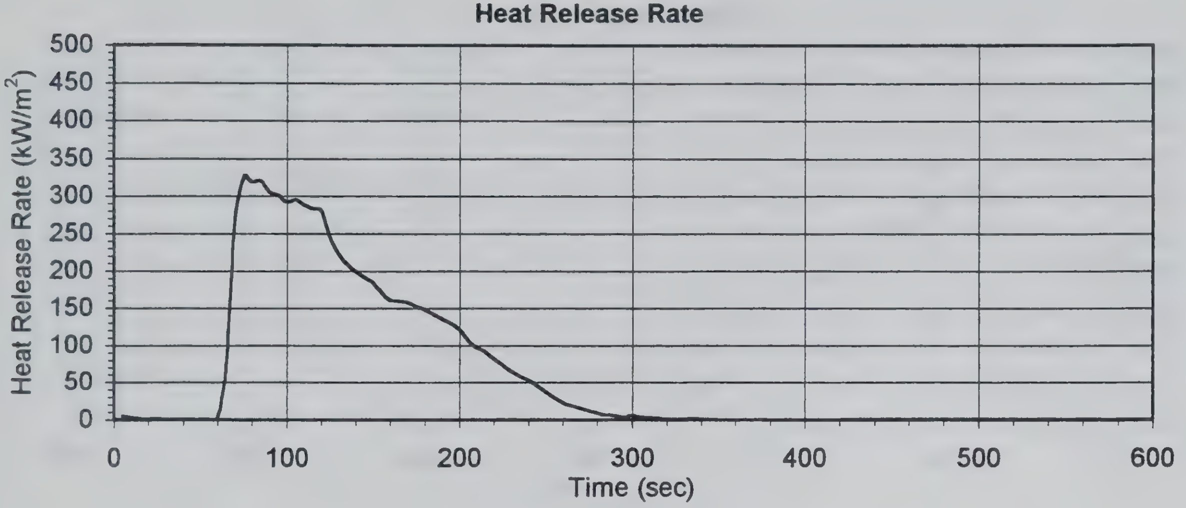
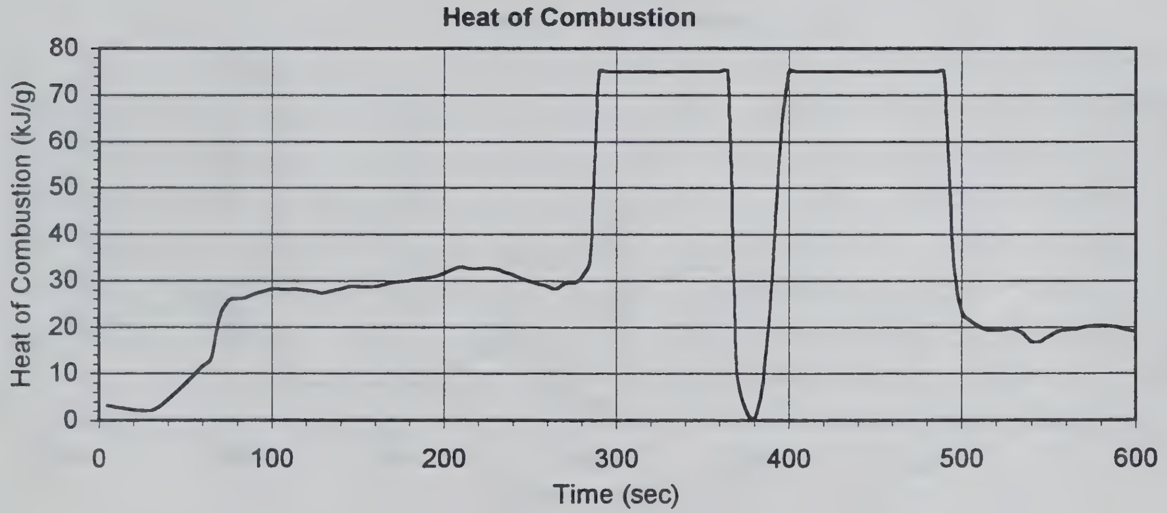


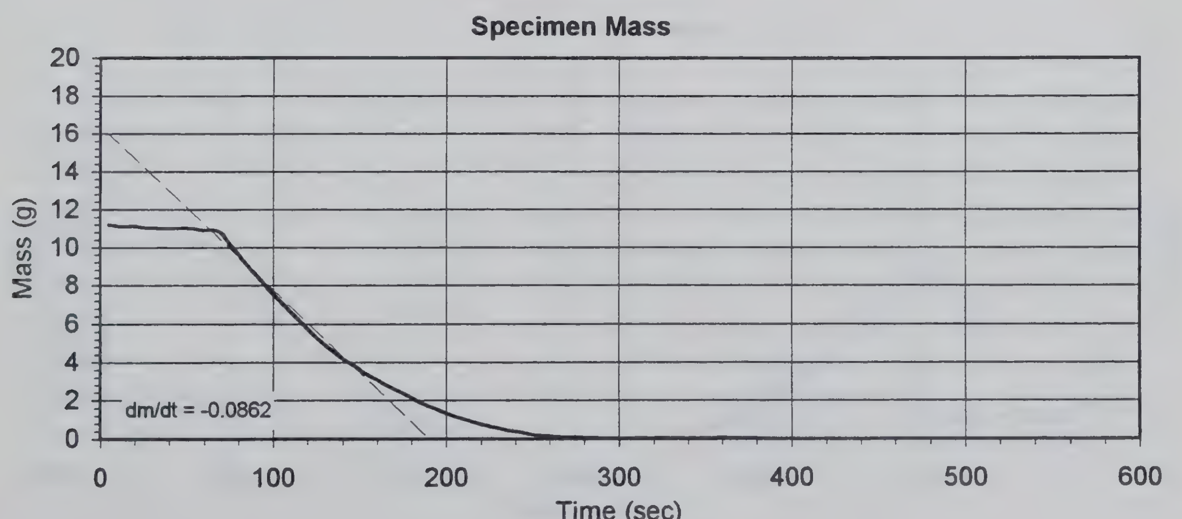




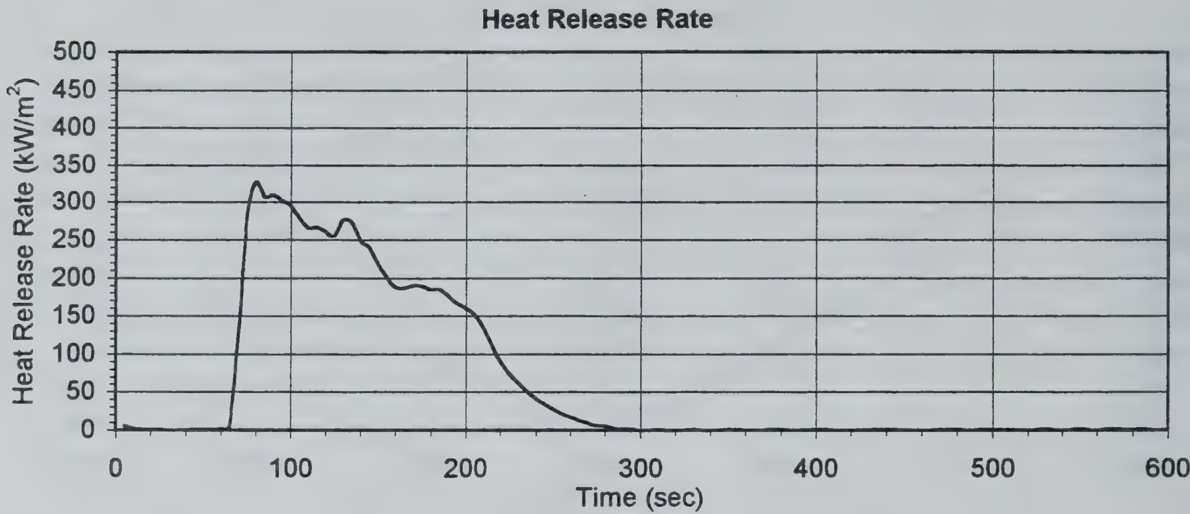
Cone Calorimeter Data R 4.20 F.R. Expanded Polystyrene Board (40 mm)
35 kW/m^2, Test #3

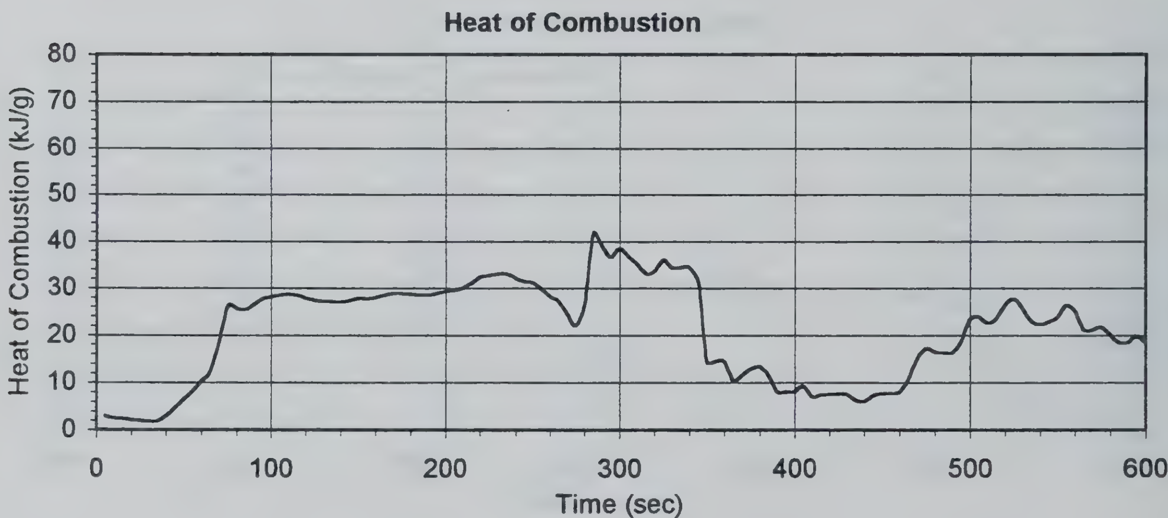


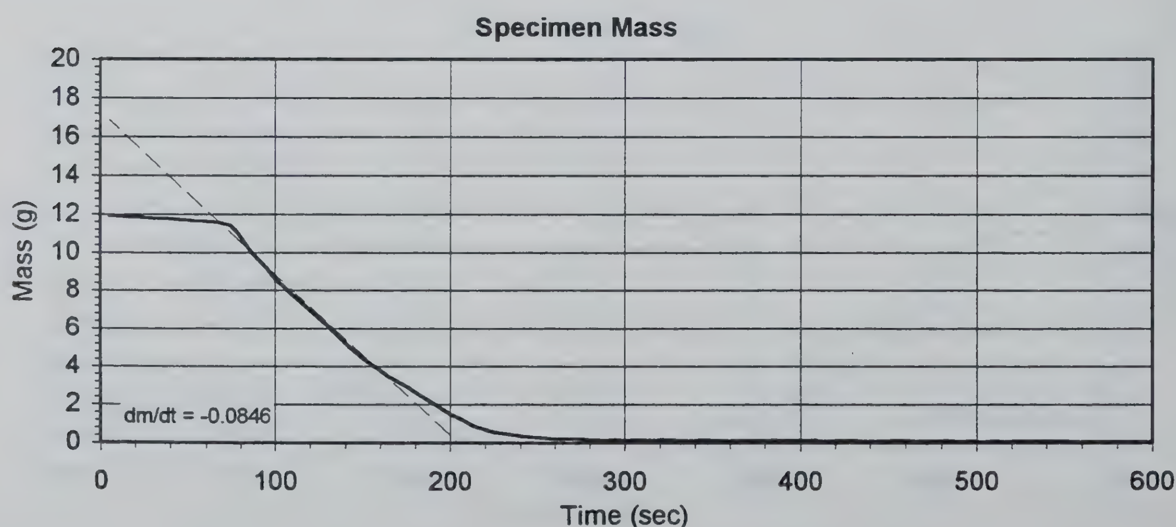




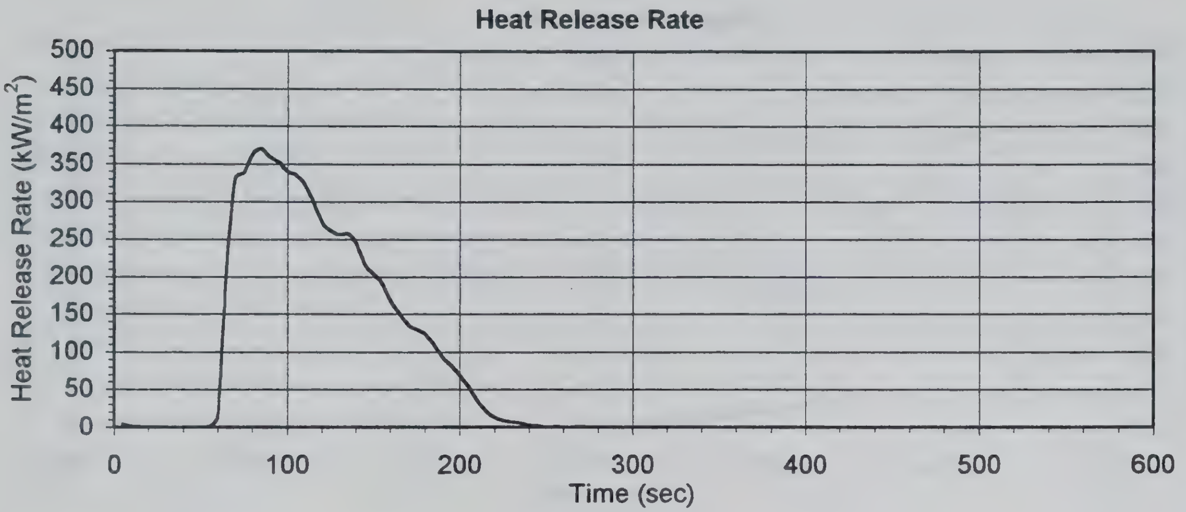
Cone Calorimeter Data R 4.20 F.R. Expanded Polystyrene Board (40 mm)
35 kW/m^2, Test #4

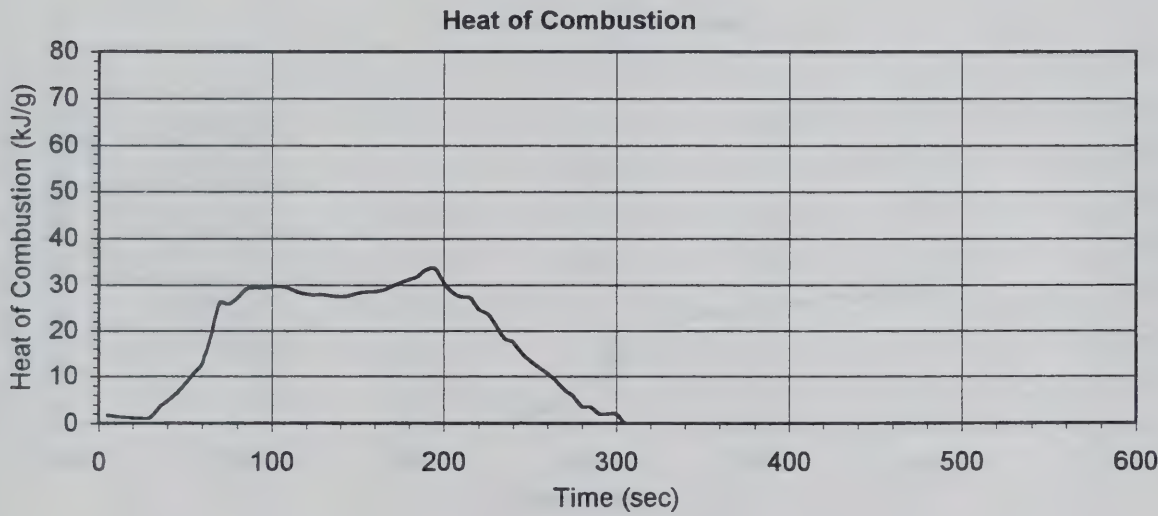


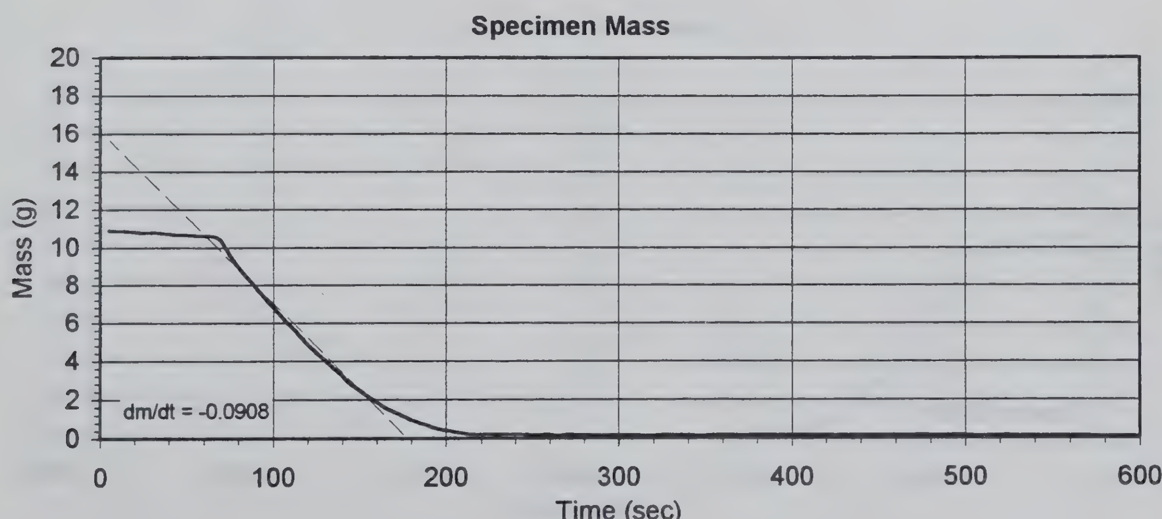




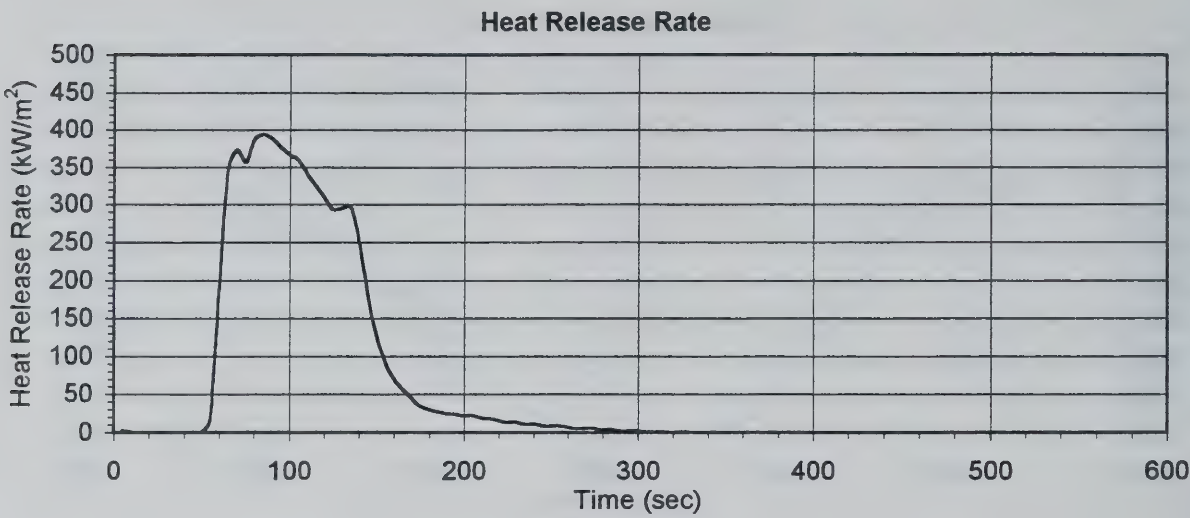
Cone Calorimeter Data R 4.20 F.R. Expanded Polystyrene Board (40 mm)
35 kW/m^2, Test #5

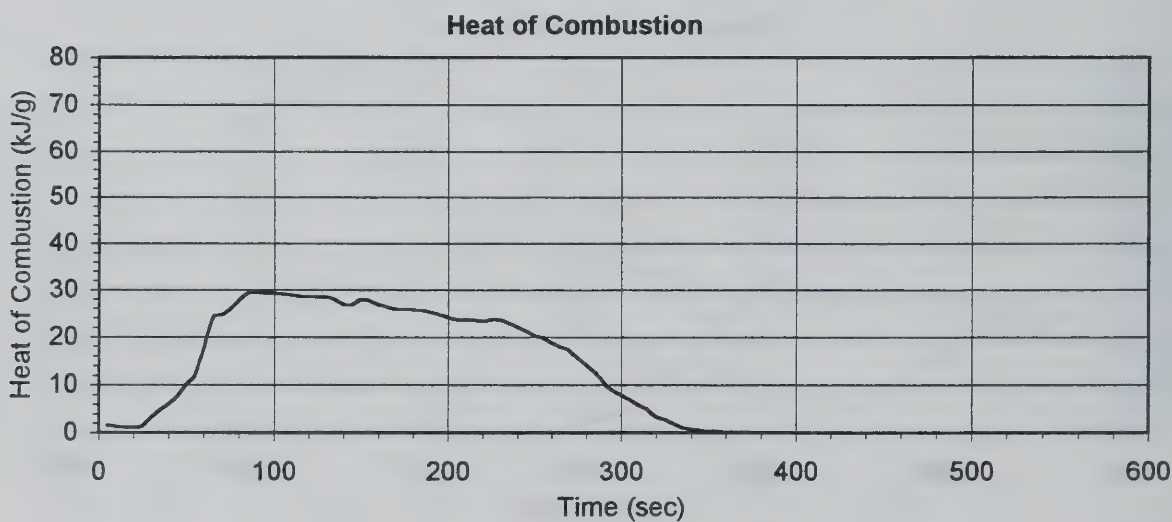


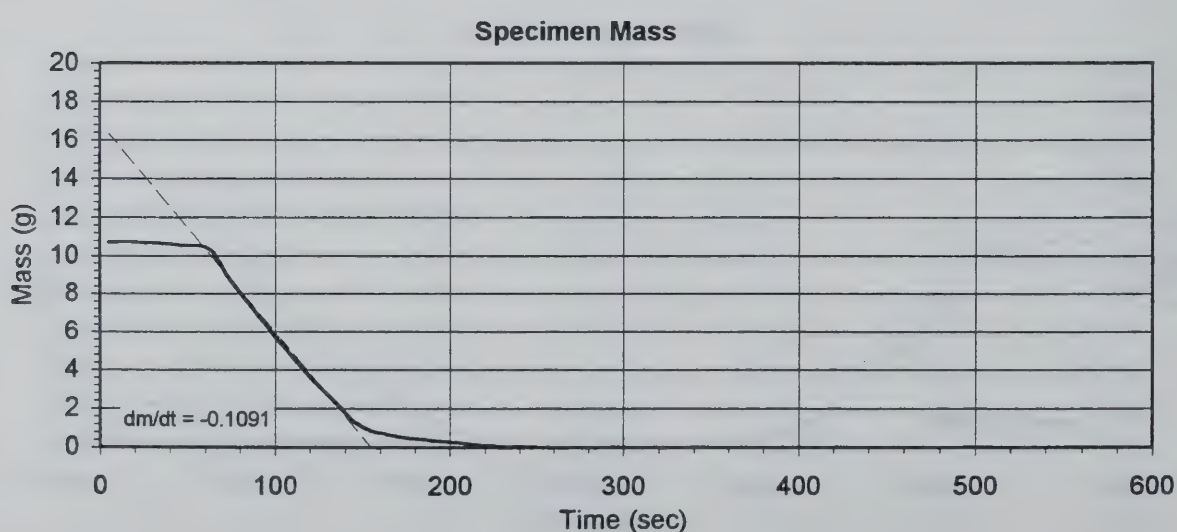




Cone Calorimeter Data R 4.20 F.R. Expanded Polystyrene Board (40 mm)
40 kW/m^2, Test #1







Cone Calorimeter Data R 4.20 F.R. Expanded Polystyrene Board (40 mm)
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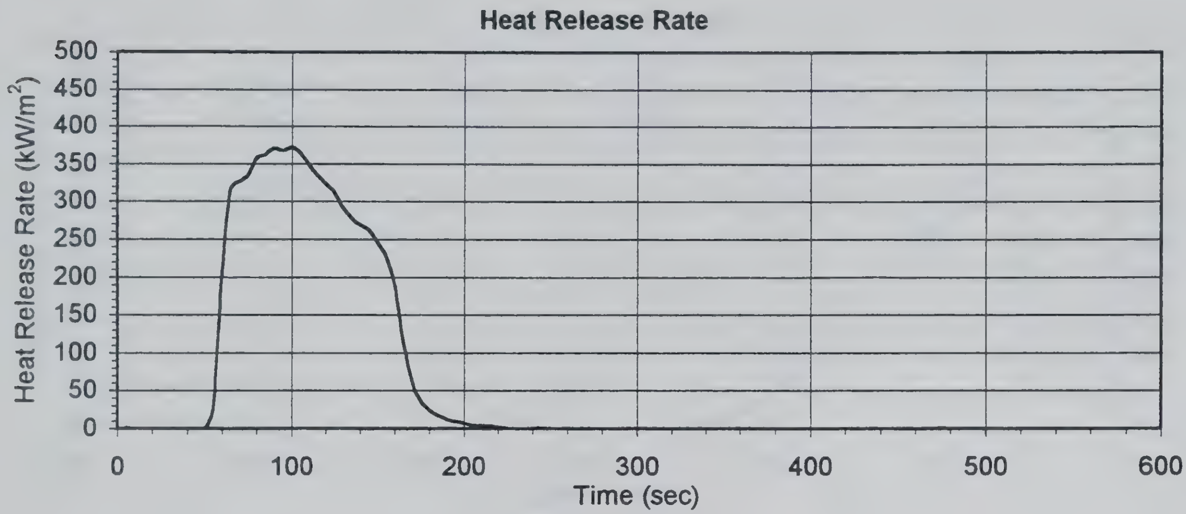
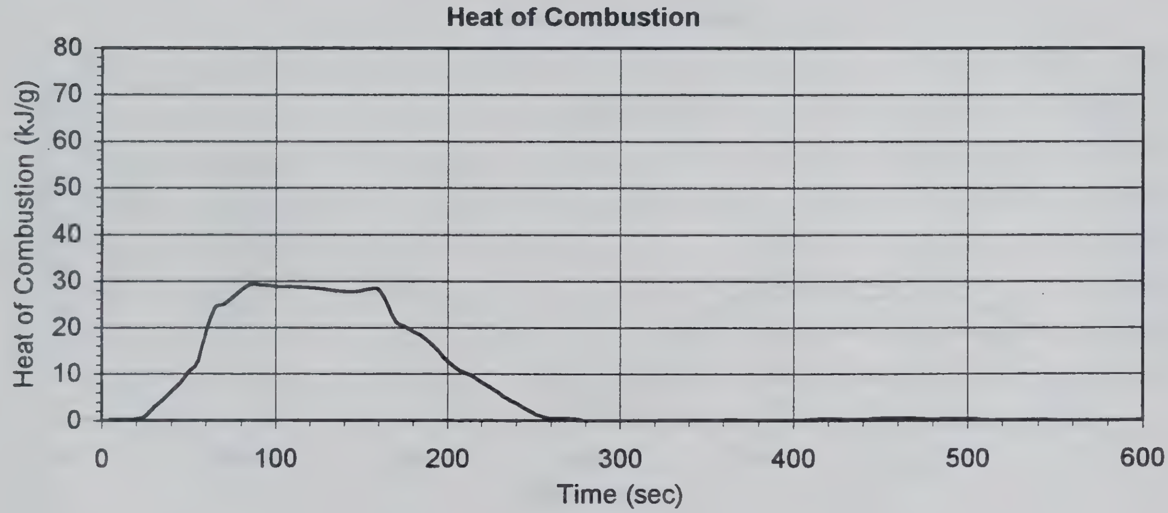
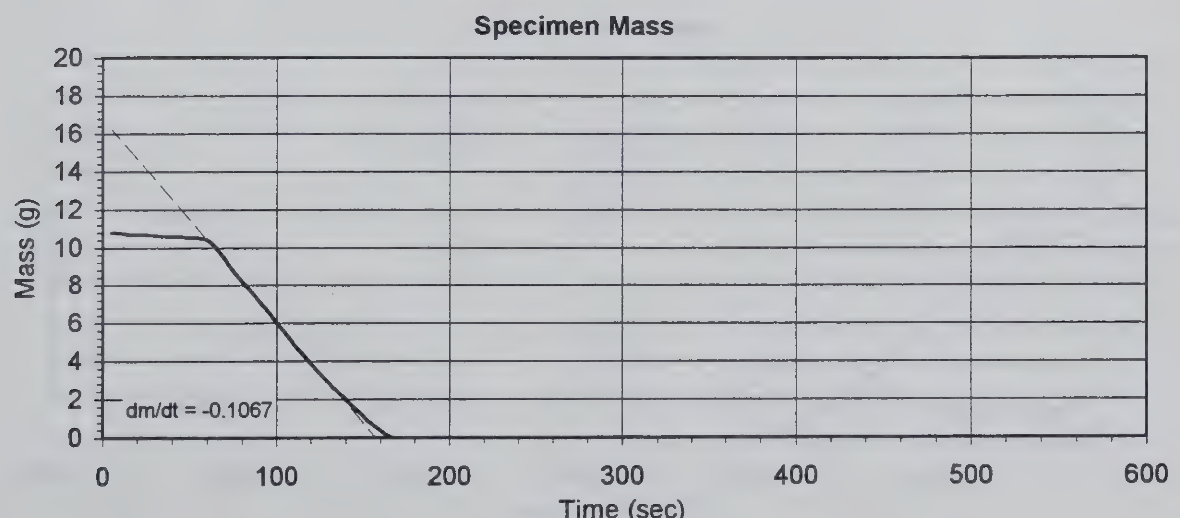
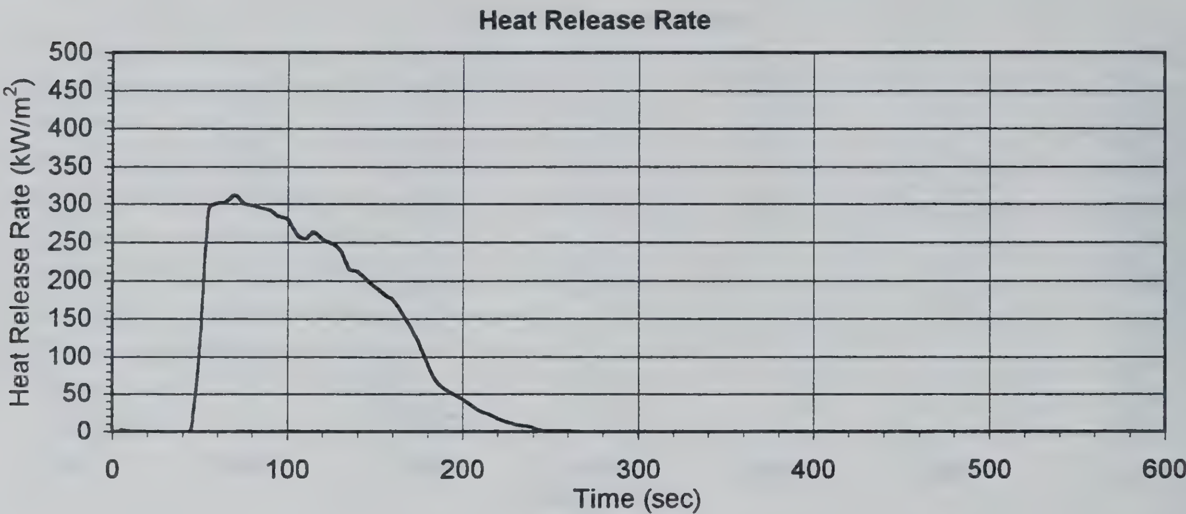
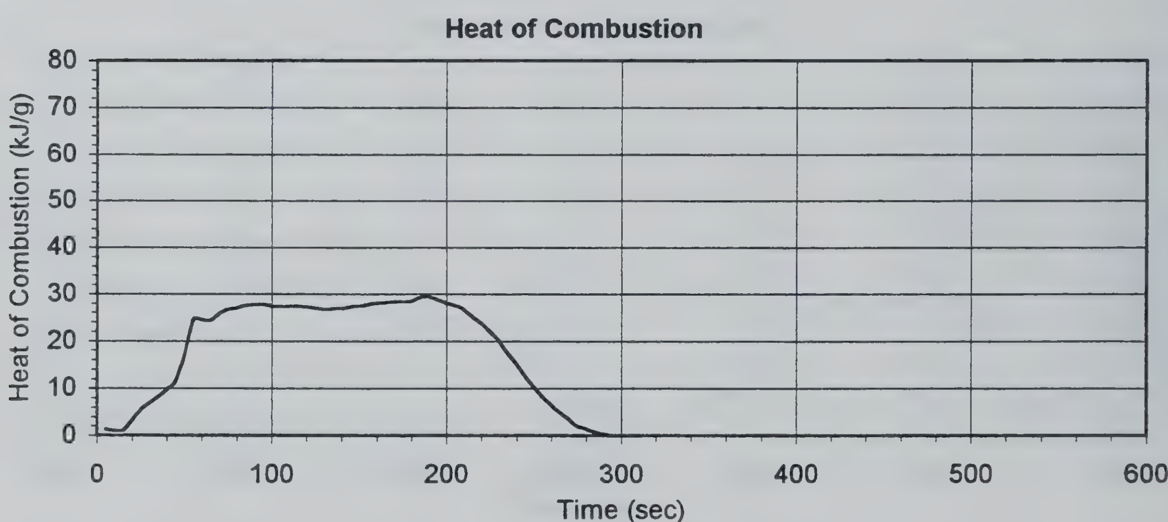


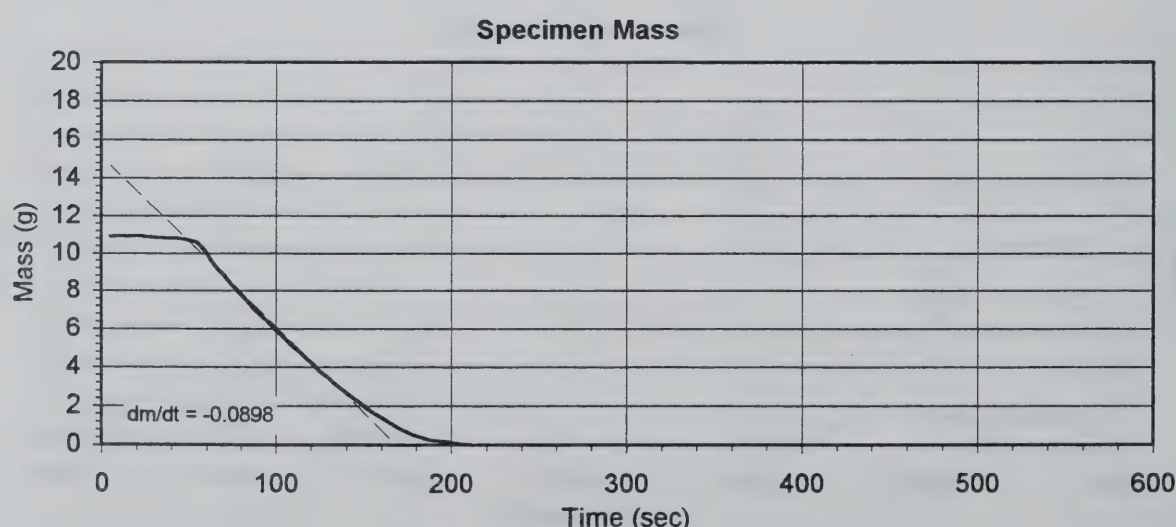




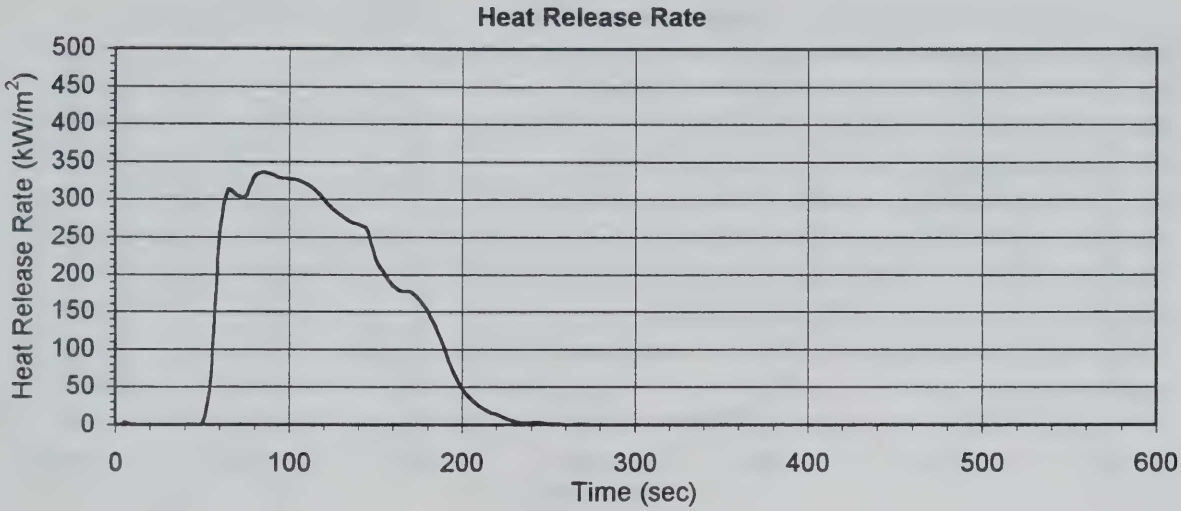
Cone Calorimeter Data R 4.20 F.R. Expanded Polystyrene Board (40 mm)
40 kW/m², Test #3

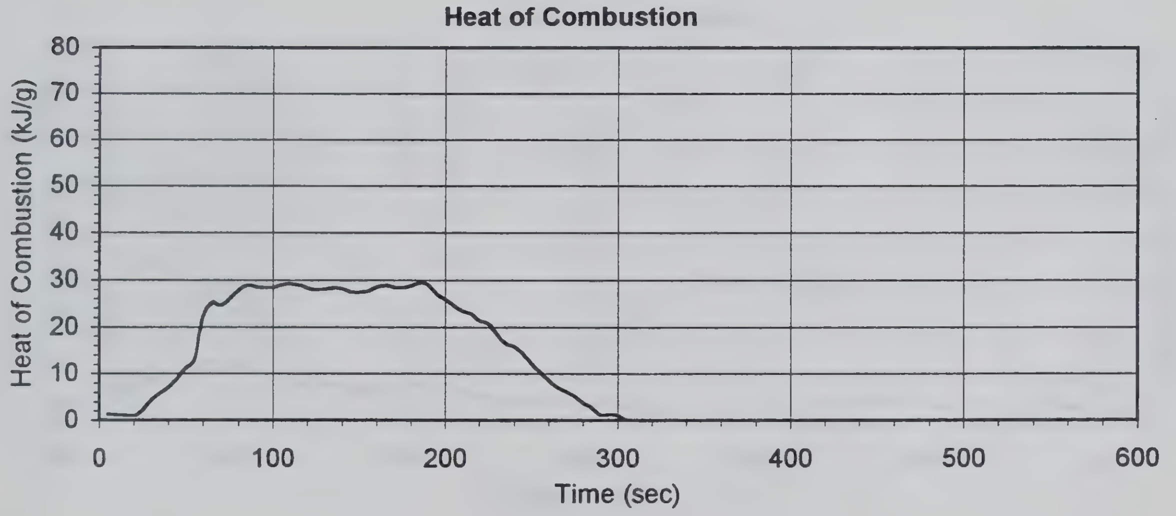


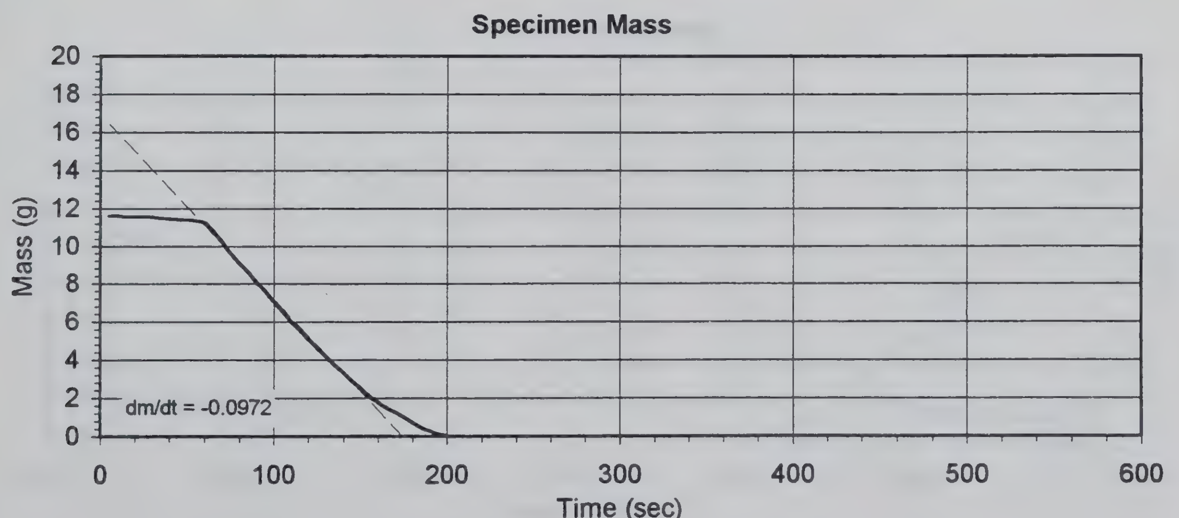




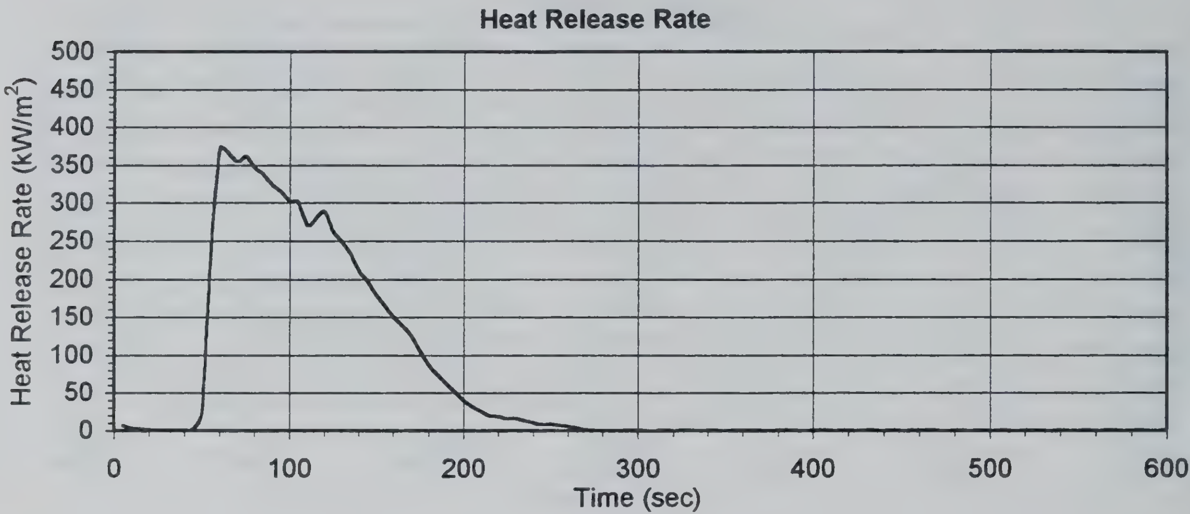
Cone Calorimeter Data R 4.20 F.R. Expanded Polystyrene Board (40 mm)
40 kW/m^2, Test #4

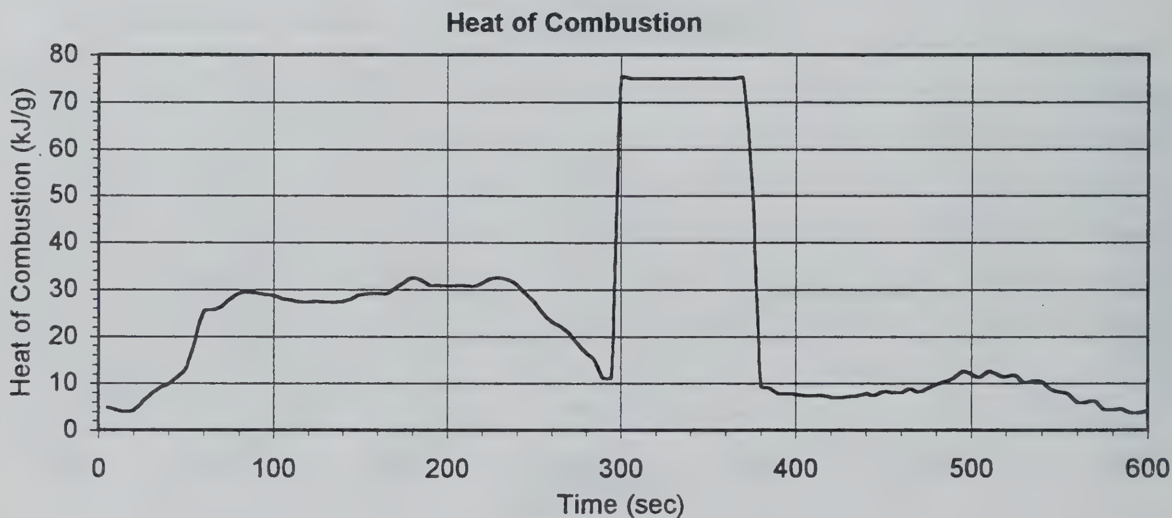


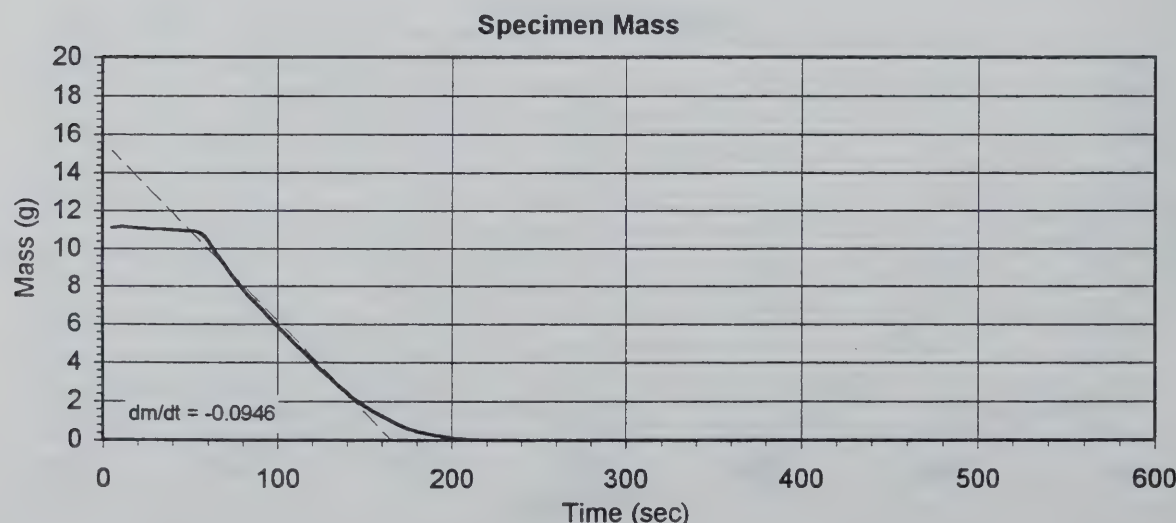




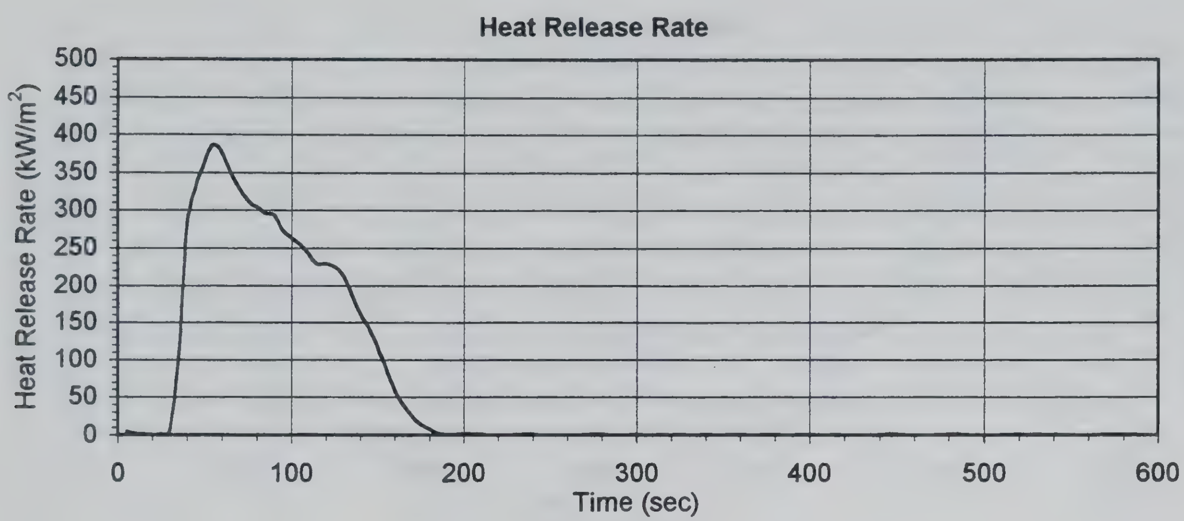
Cone Calorimeter Data R 4.20 F.R. Expanded Polystyrene Board (40 mm)
40 kW/m^2, Test #5

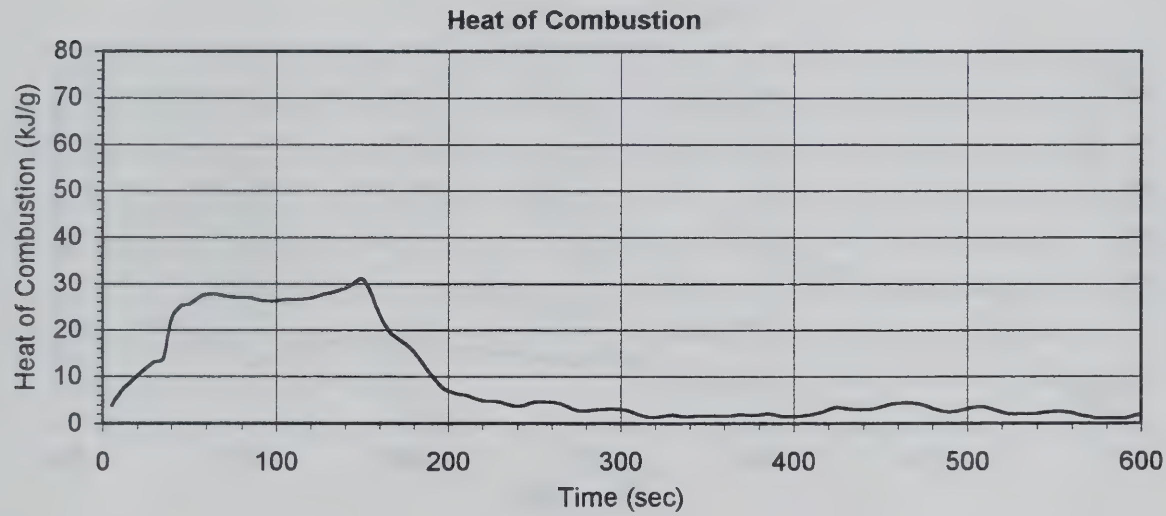


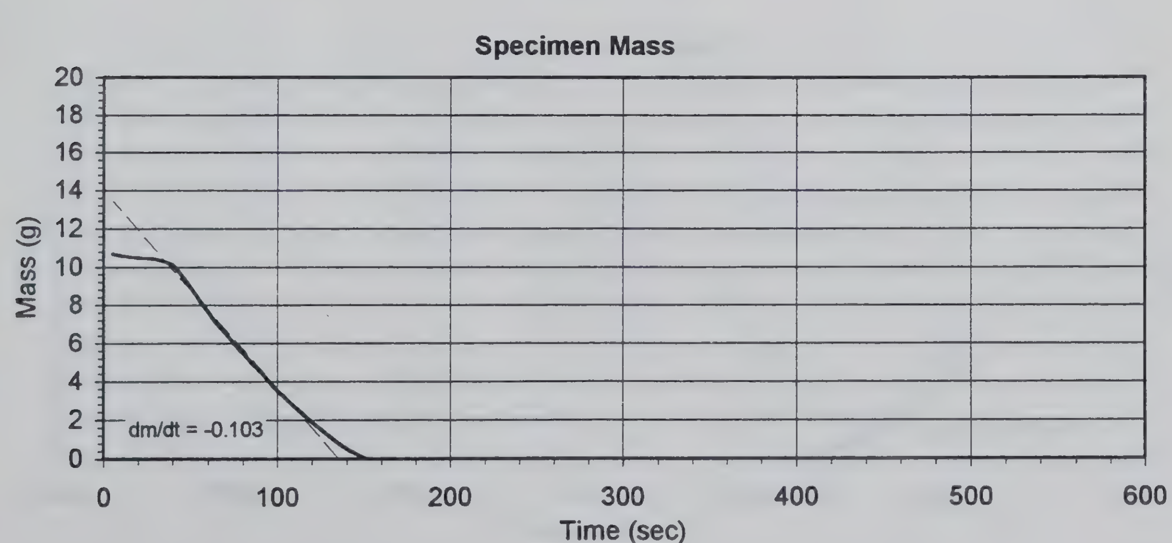




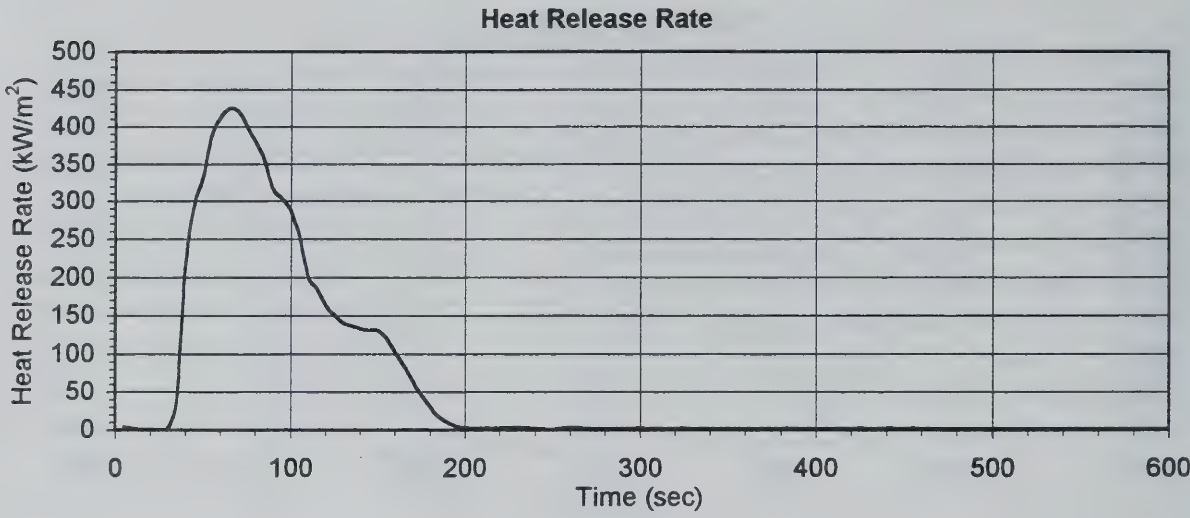
Cone Calorimeter Data R 4.20 F.R. Expanded Polystyrene Board (40 mm)
50 kW/m^2, Test #1

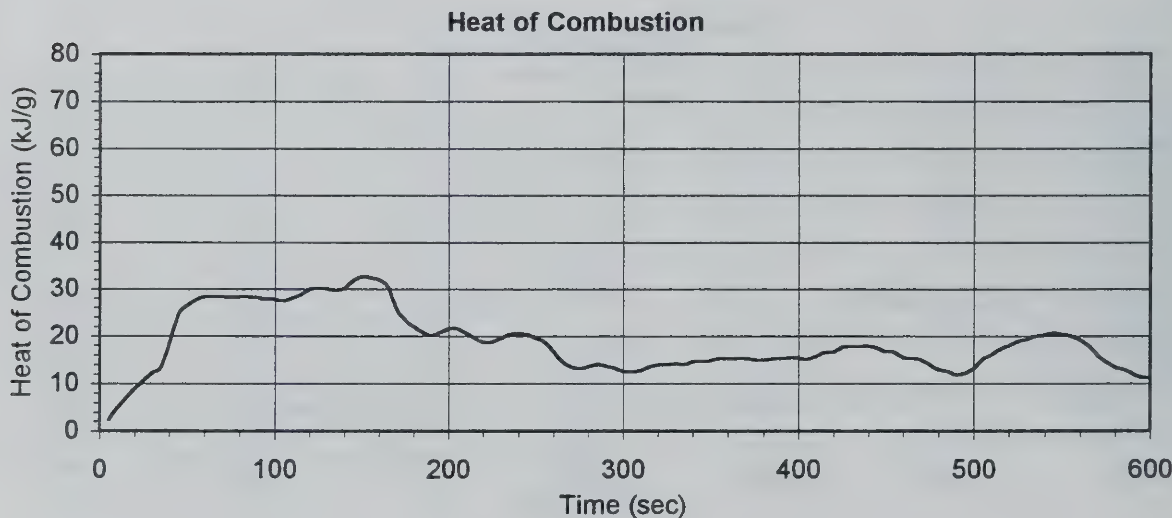


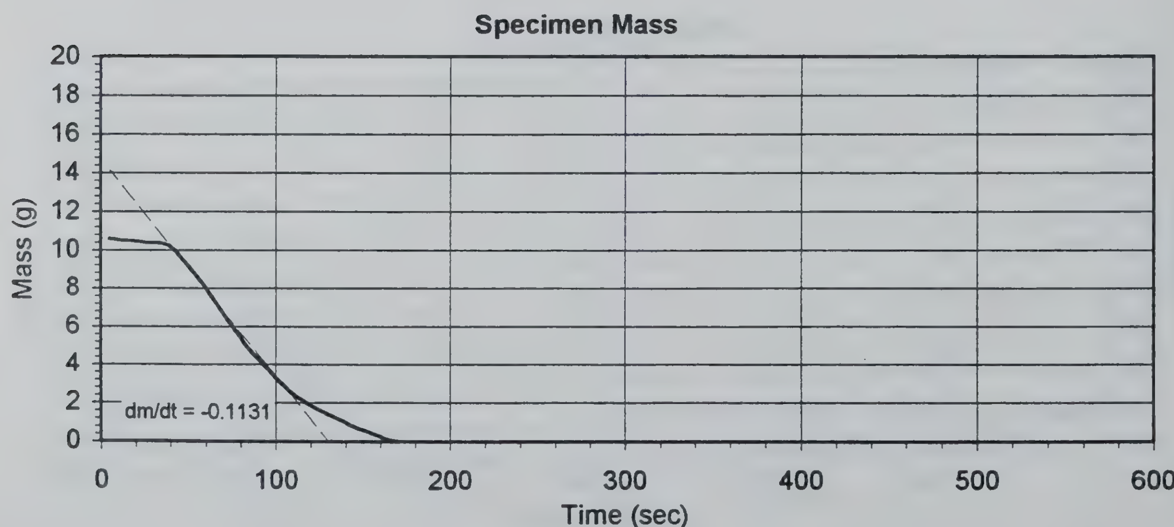




Cone Calorimeter Data R 4.20 F.R. Expanded Polystyrene Board (40 mm)
50 kW/m², Test #2

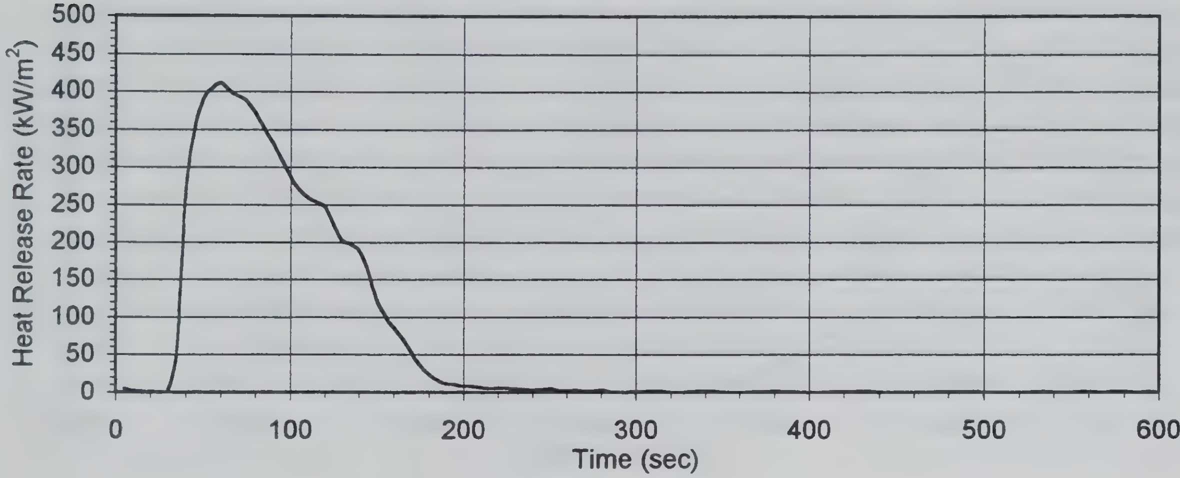




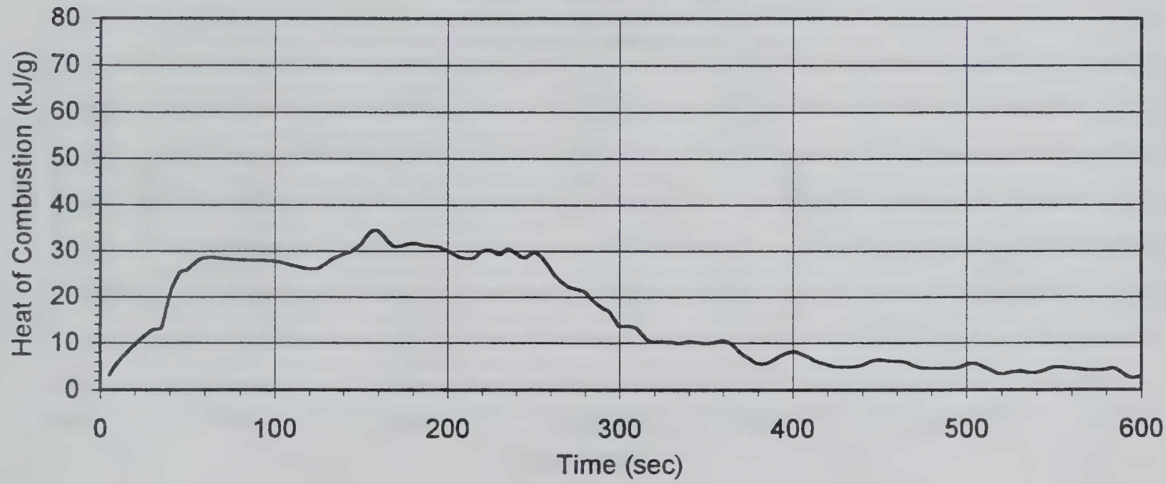


Cone Calorimeter Data R 4.20 F.R. Expanded Polystyrene Board (40 mm)
50 kW/m^2, Test #3

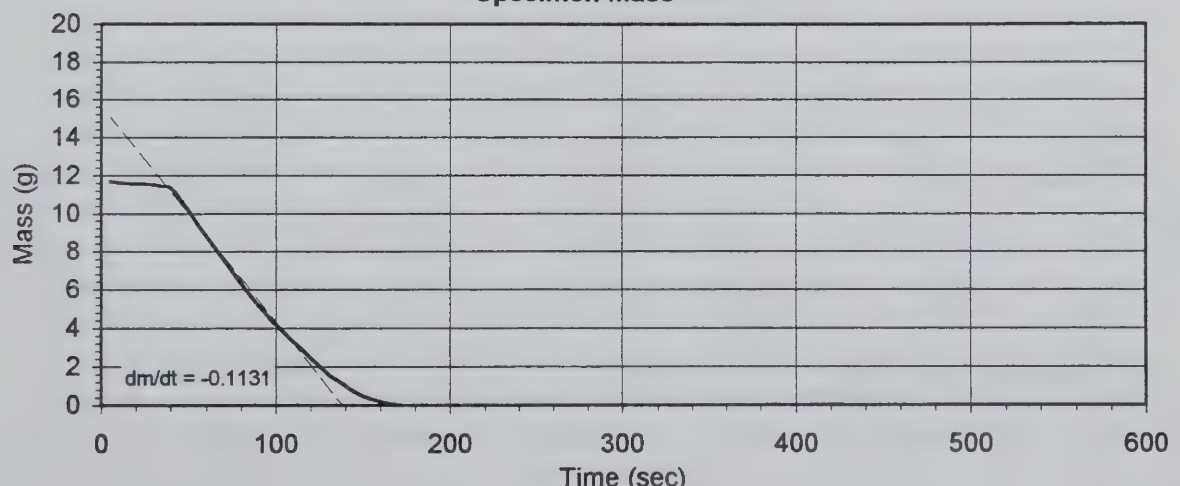
Heat Release Rate



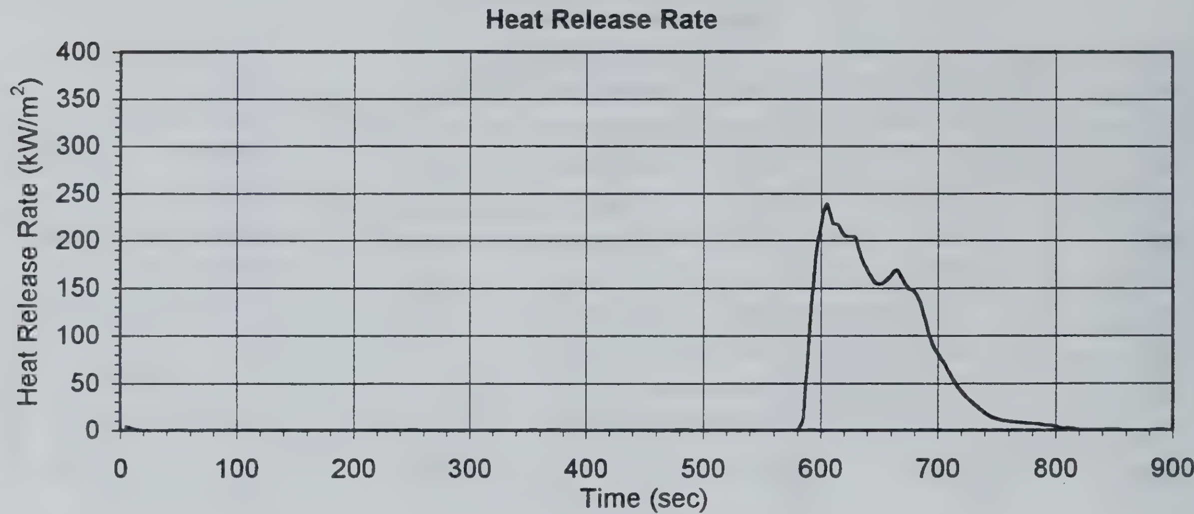
Heat of Combustion

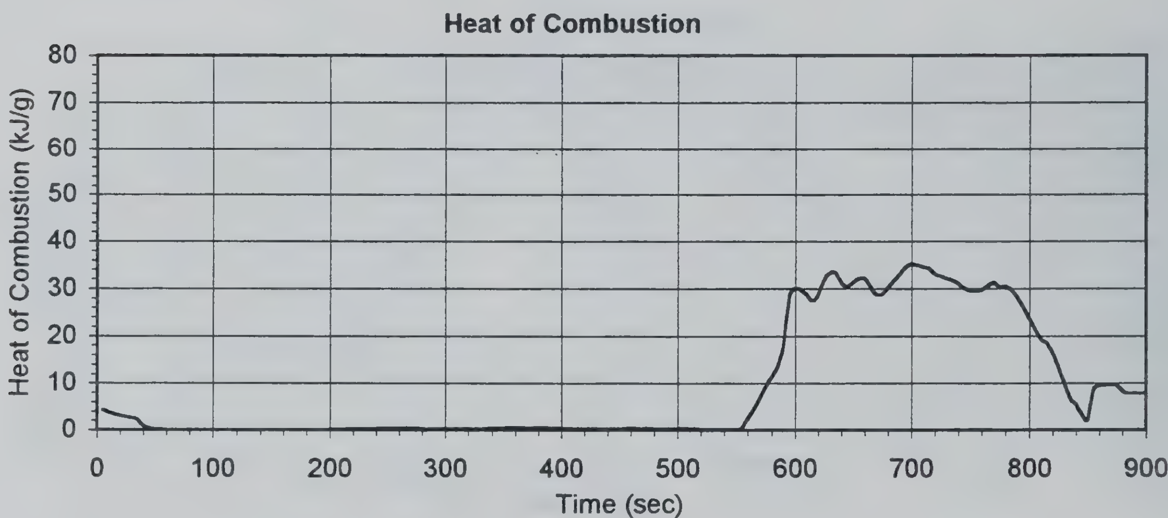


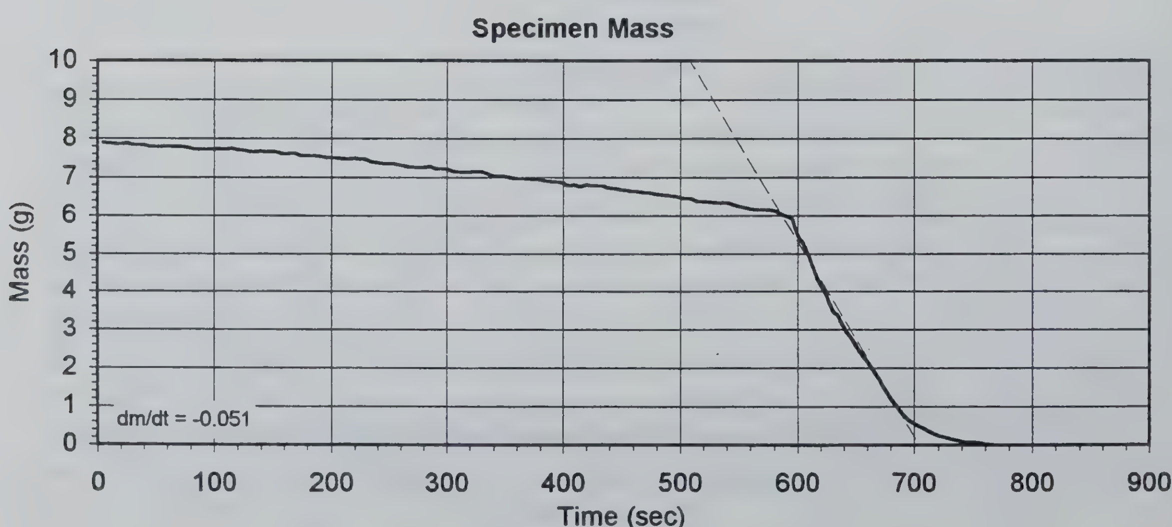
Specimen Mass



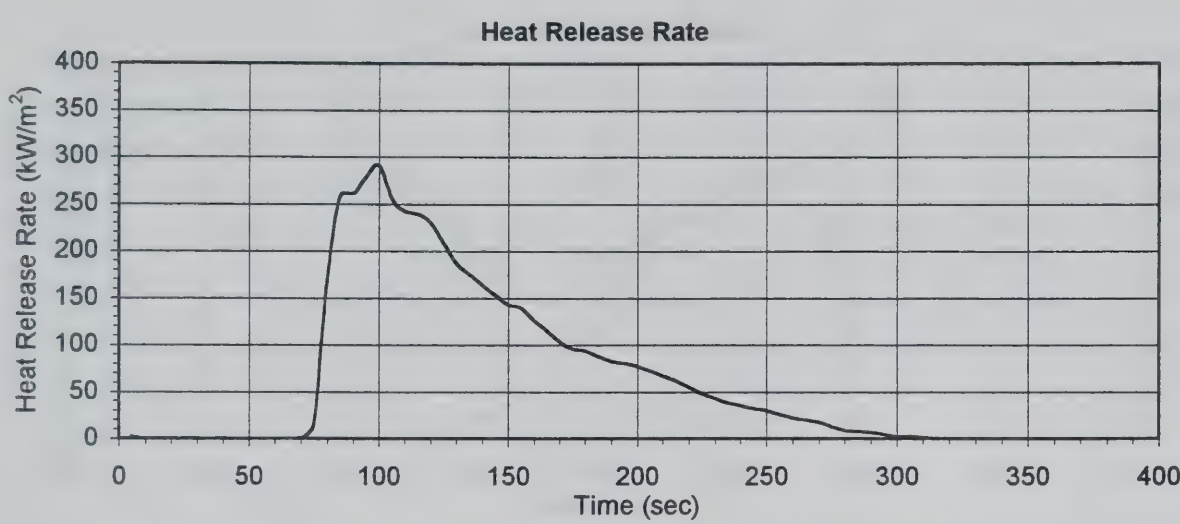
Cone Calorimeter Data R 4.21 F.R. Expanded Polystyrene Board (80 mm)
25 kW/m^2, Test #4

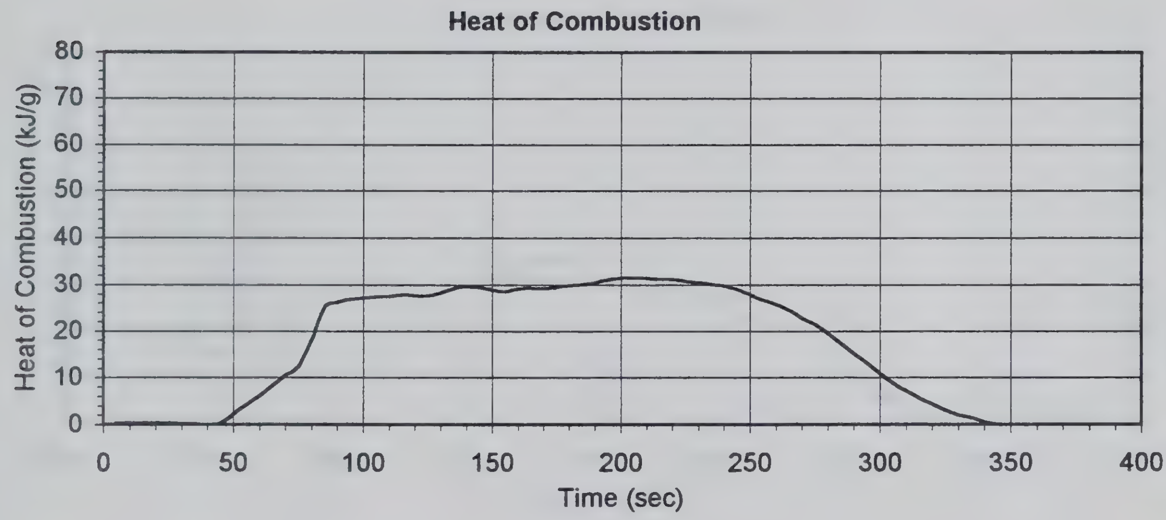


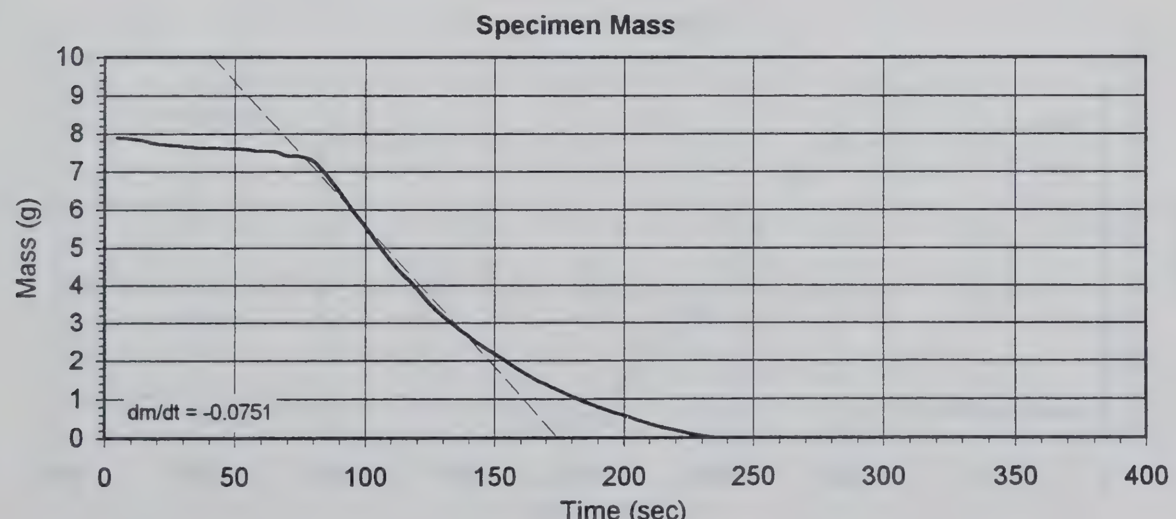




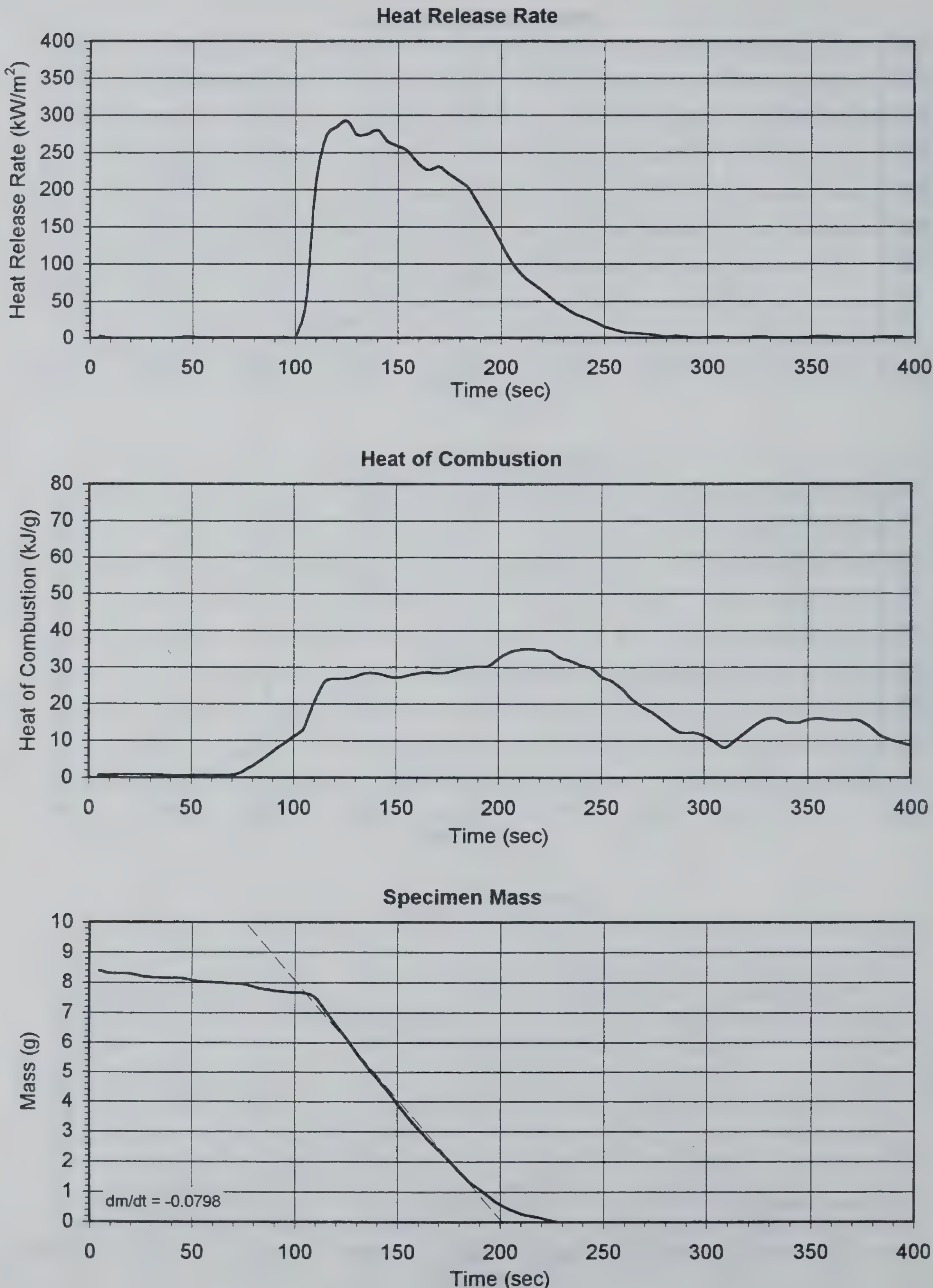
Cone Calorimeter Data R 4.21 F.R. Expanded Polystyrene Board (80 mm)
35 kW/m^2, Test #1



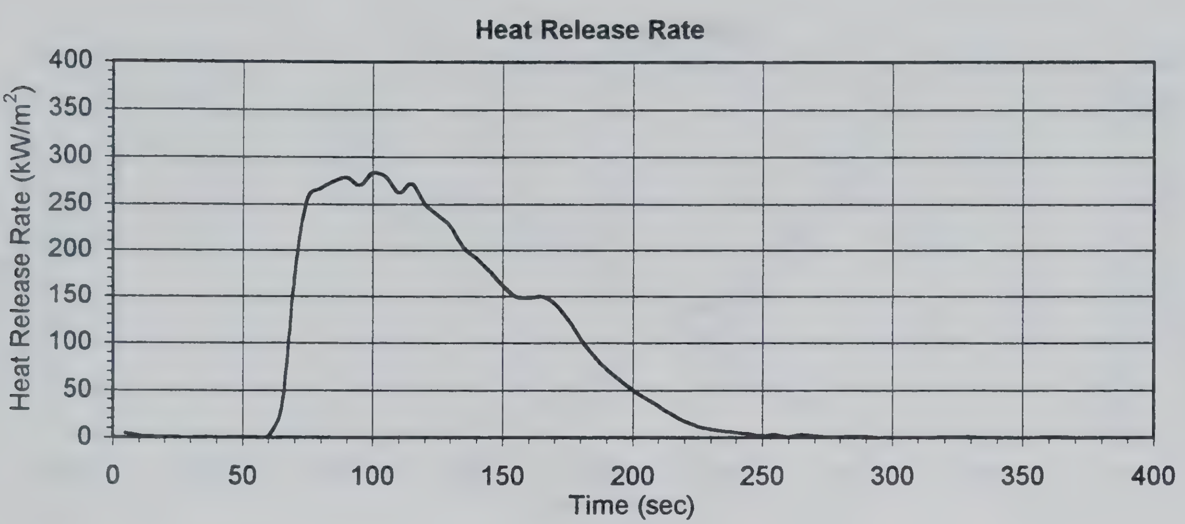


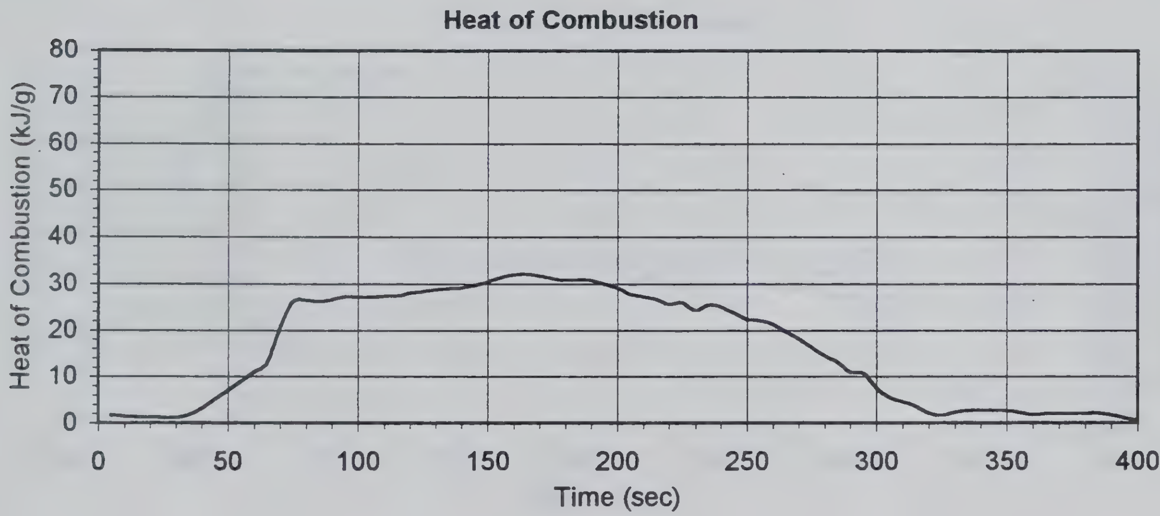


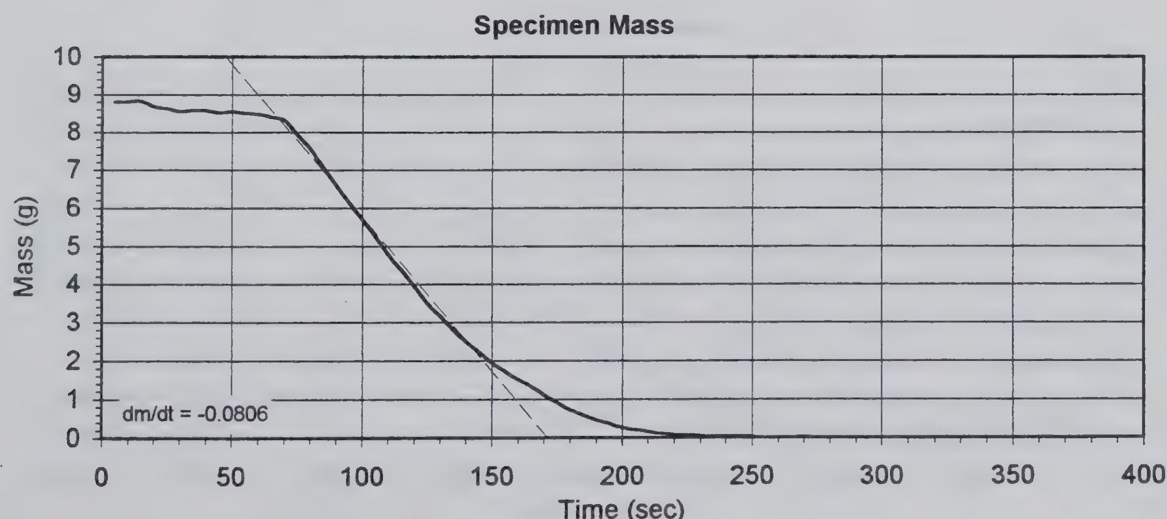
Cone Calorimeter Data R 4.21 F.R. Expanded Polystyrene Board (80 mm)
35 kW/m^2, Test #2



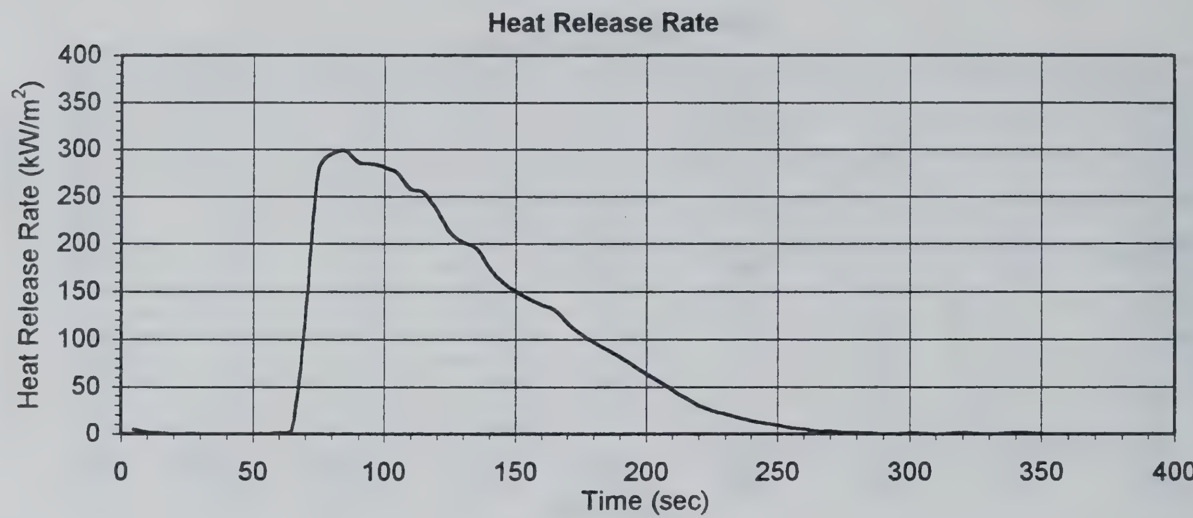
Cone Calorimeter Data R 4.21 F.R. Expanded Polystyrene Board (80 mm)
35 kW/m^2, Test #3

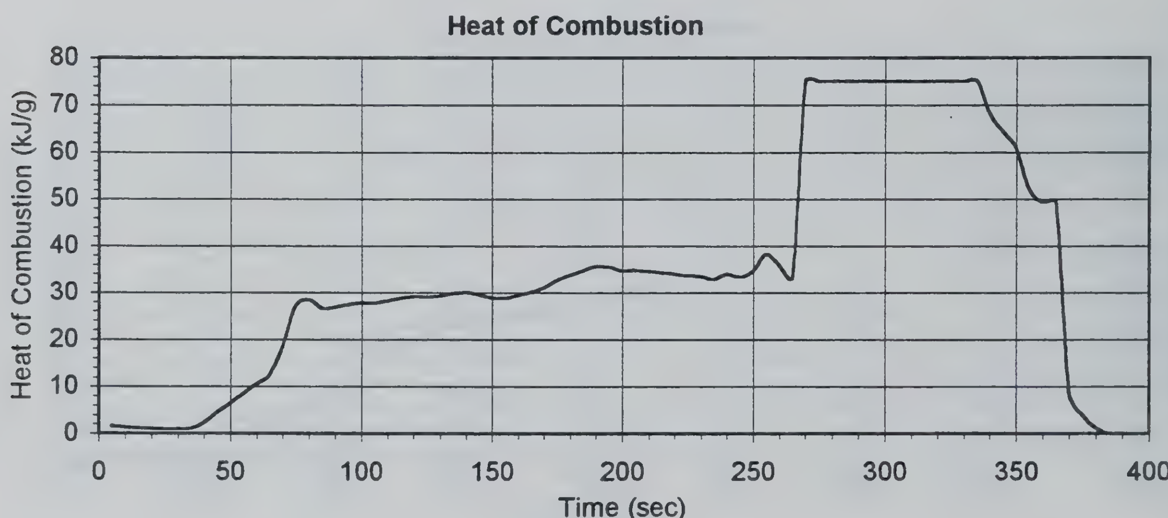


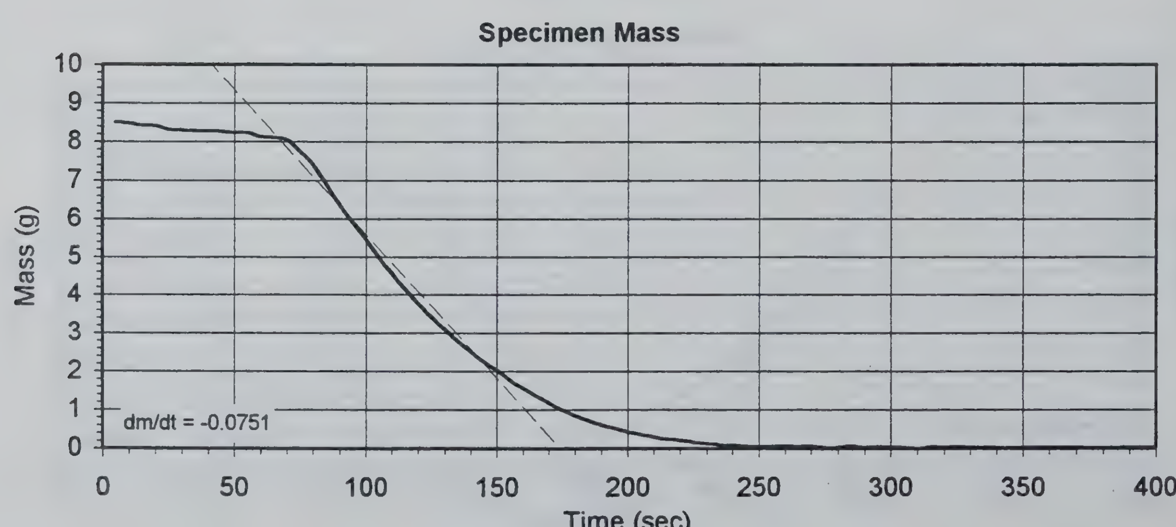




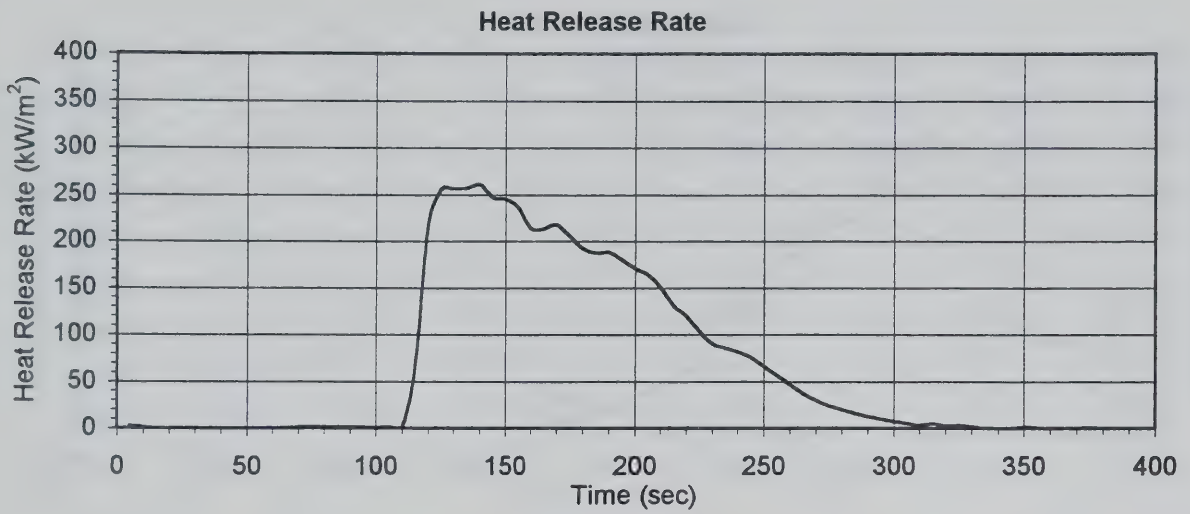
Cone Calorimeter Data R 4.21 F.R. Expanded Polystyrene Board (80 mm)
35 kW/m^2, Test #4

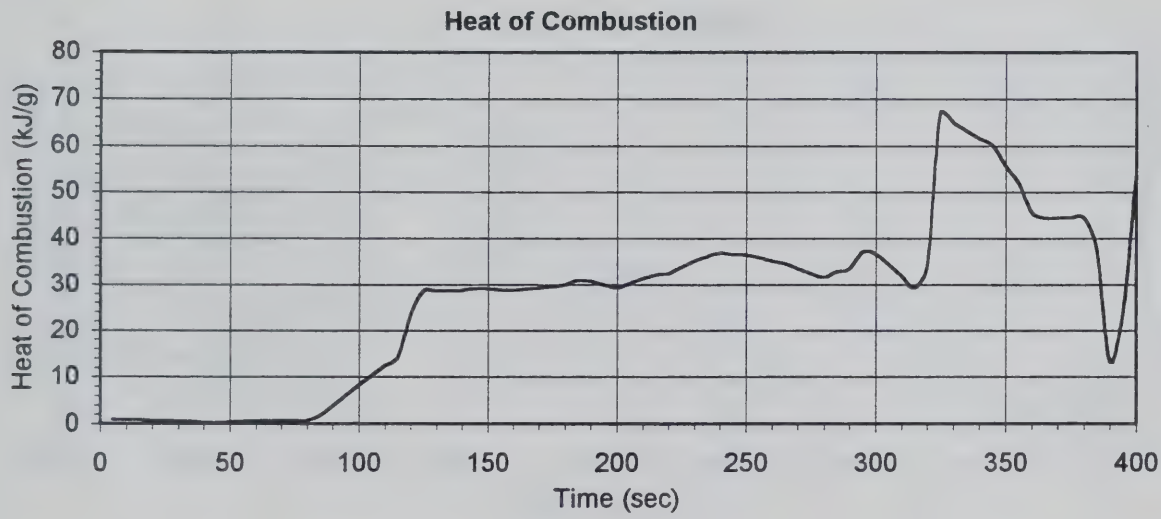


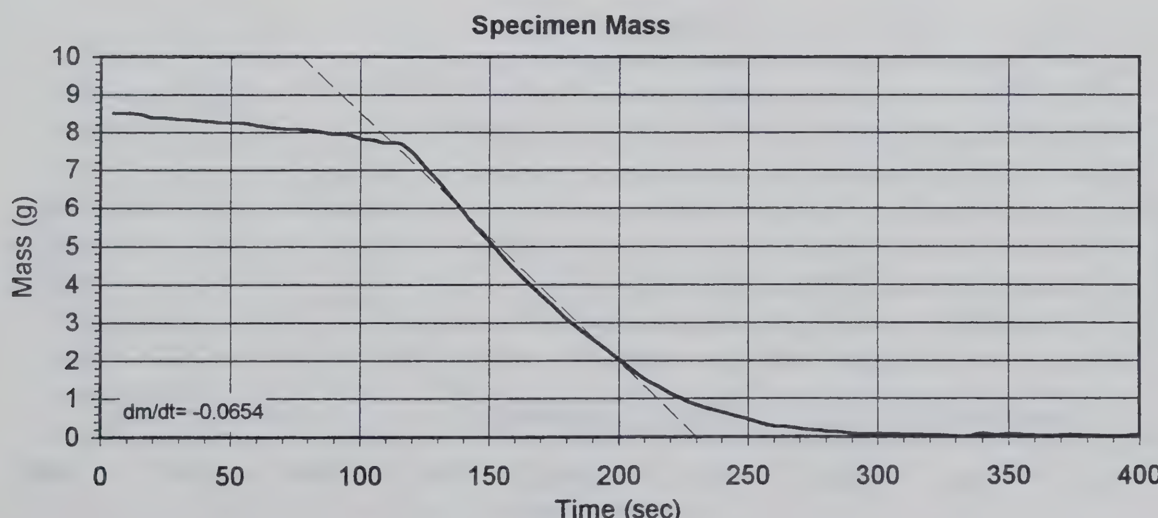




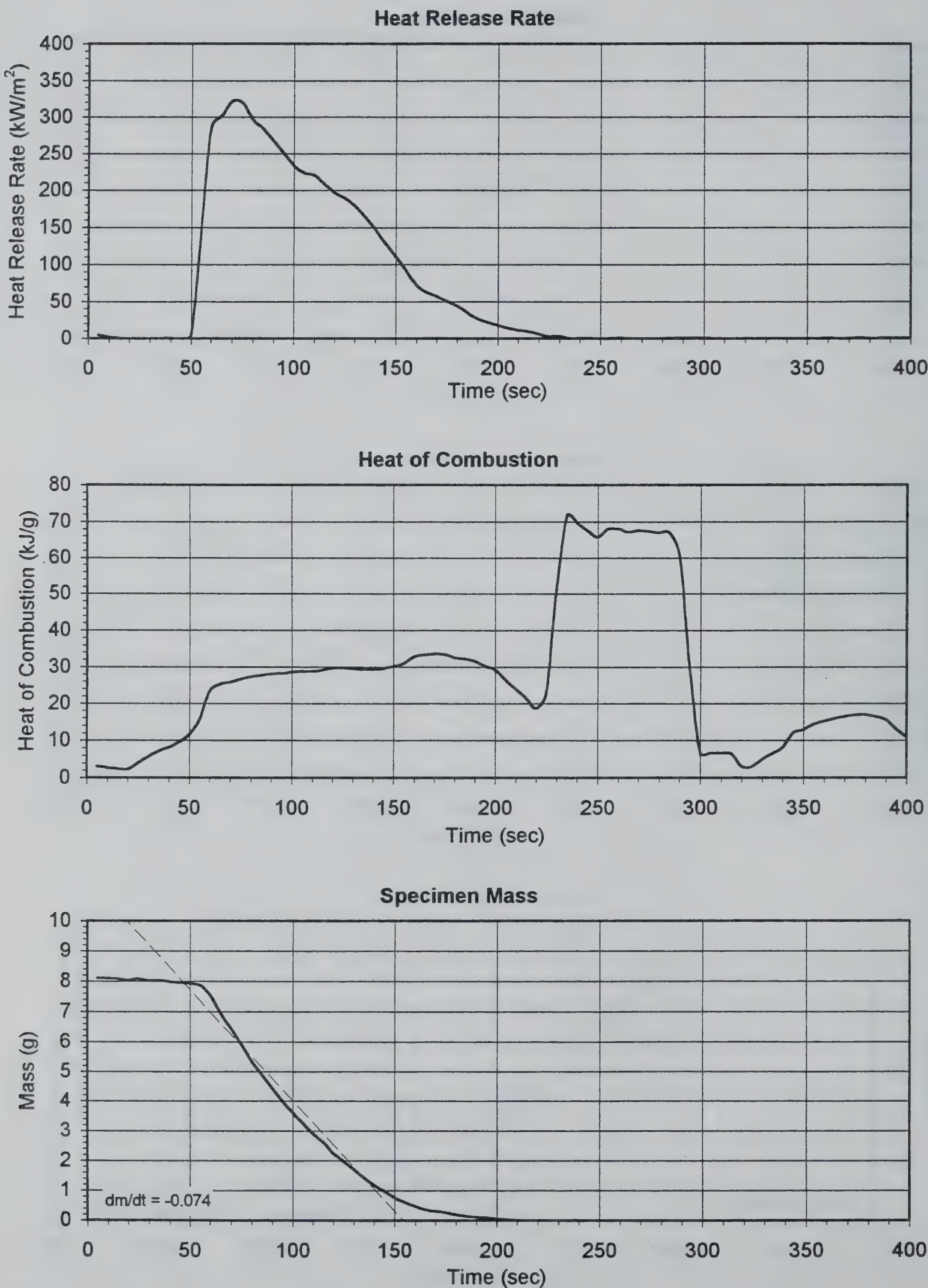
Cone Calorimeter Data R 4.21 F.R. Expanded Polystyrene Board (80 mm)
35 kW/m^2, Test #5







Cone Calorimeter Data R 4.21 F.R. Expanded Polystyrene Board (80 mm)
40 kW/m^2, Test #1



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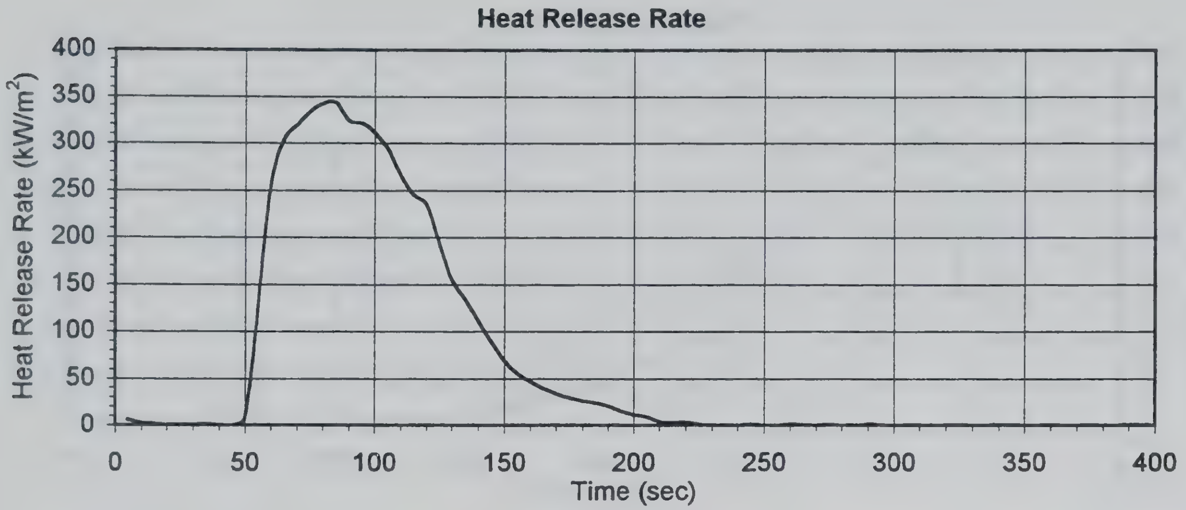
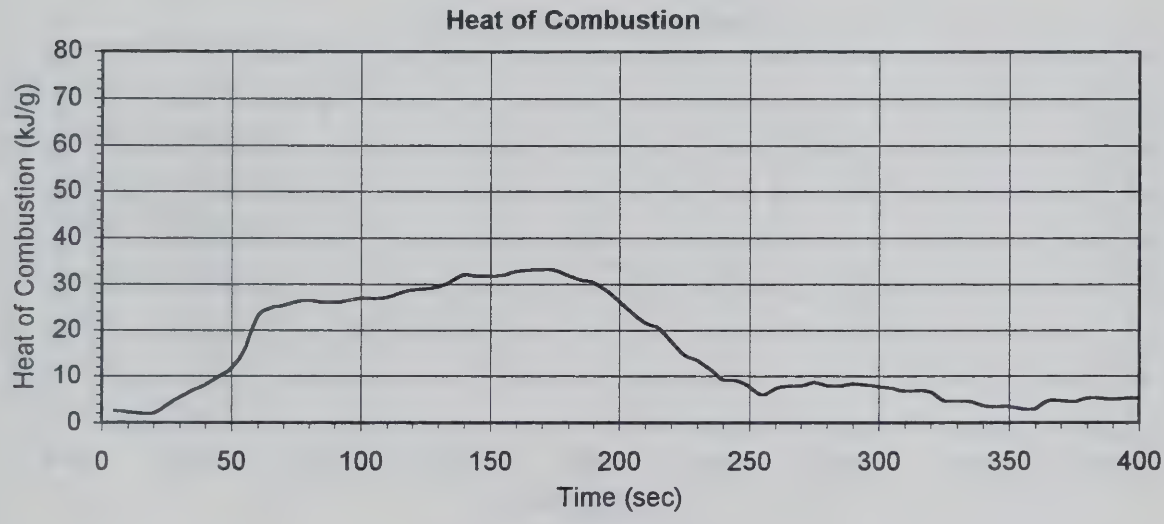
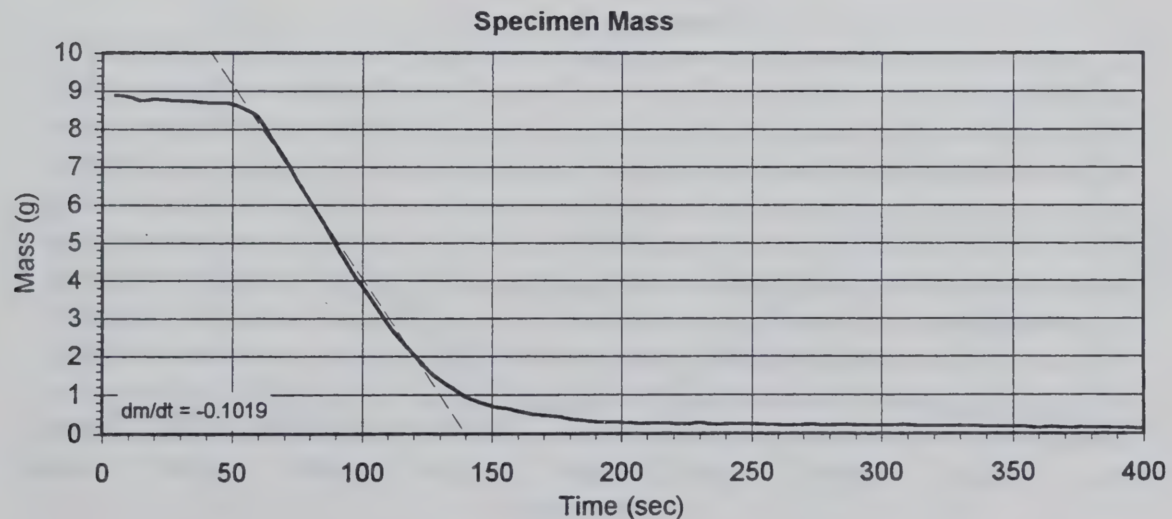
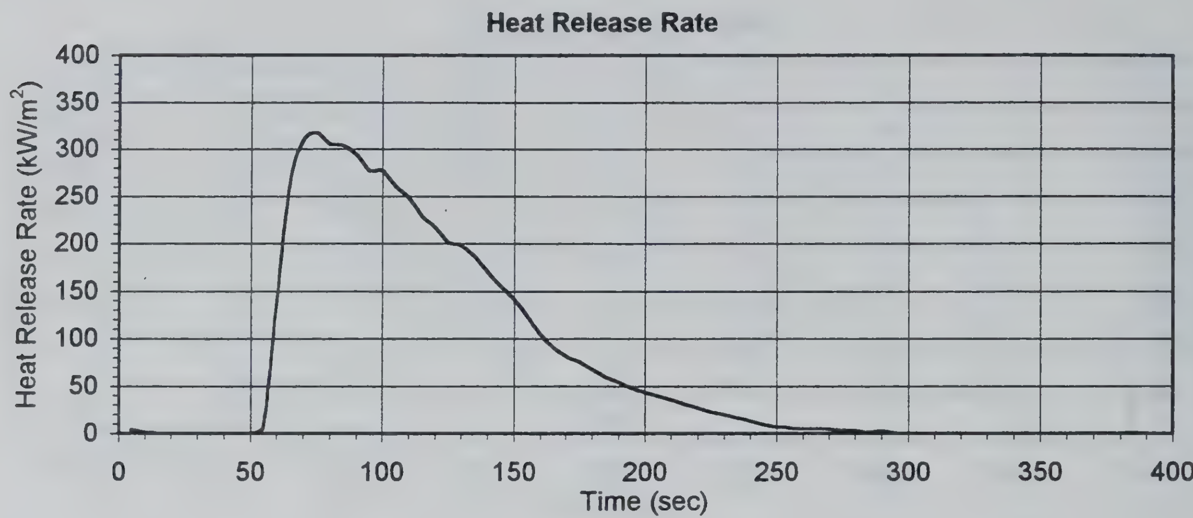
40 kW/m^2, Test #2

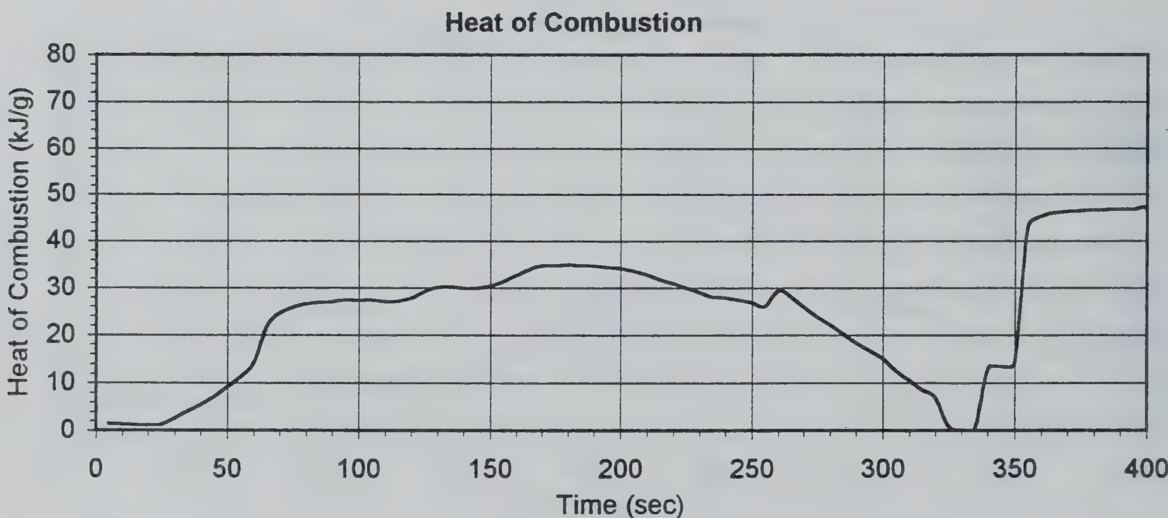


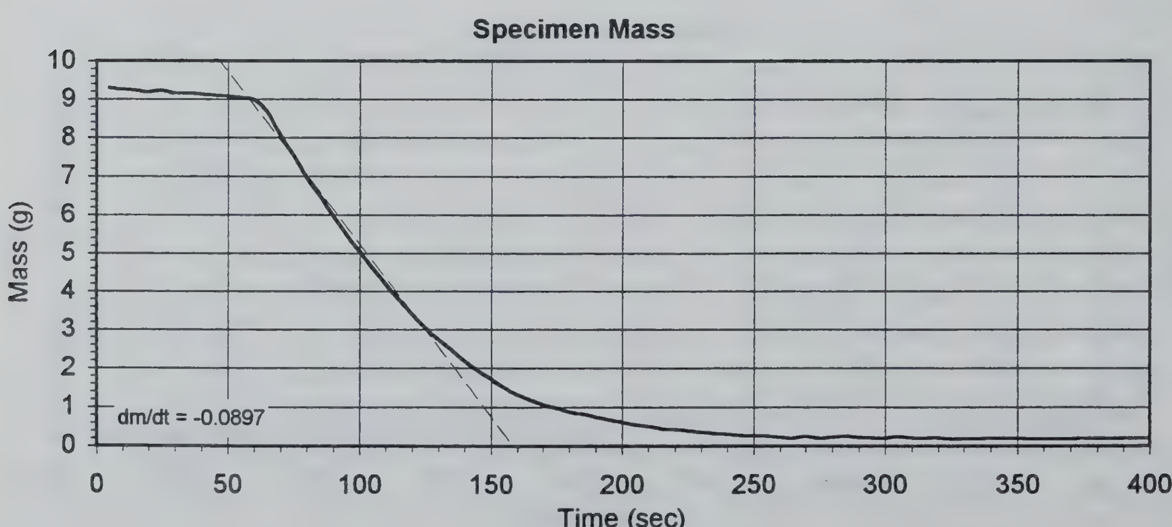




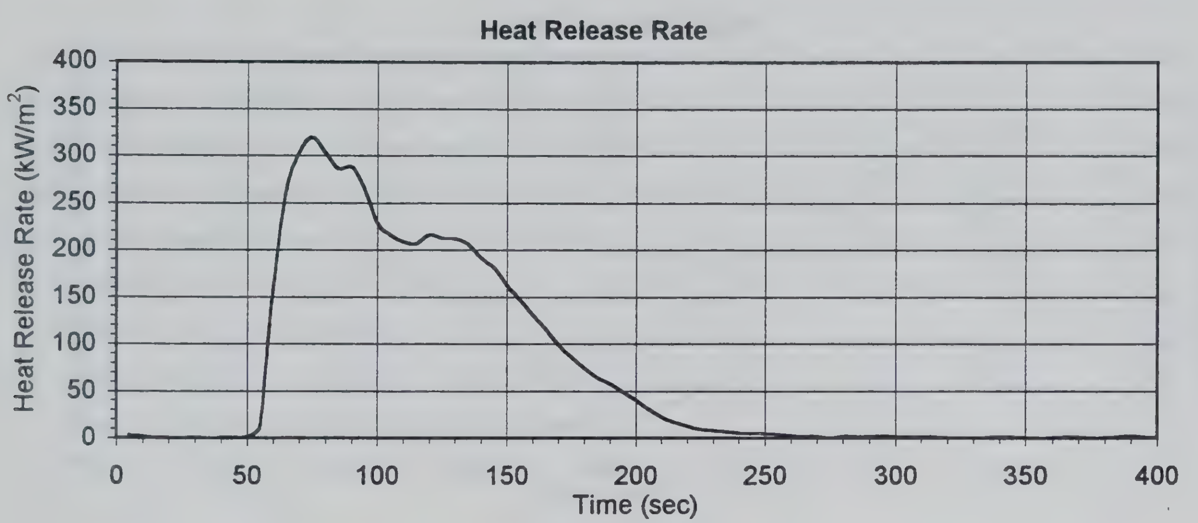
Cone Calorimeter Data R 4.21 F.R. Expanded Polystyrene Board (80 mm)
40 kW/m^2, Test #3

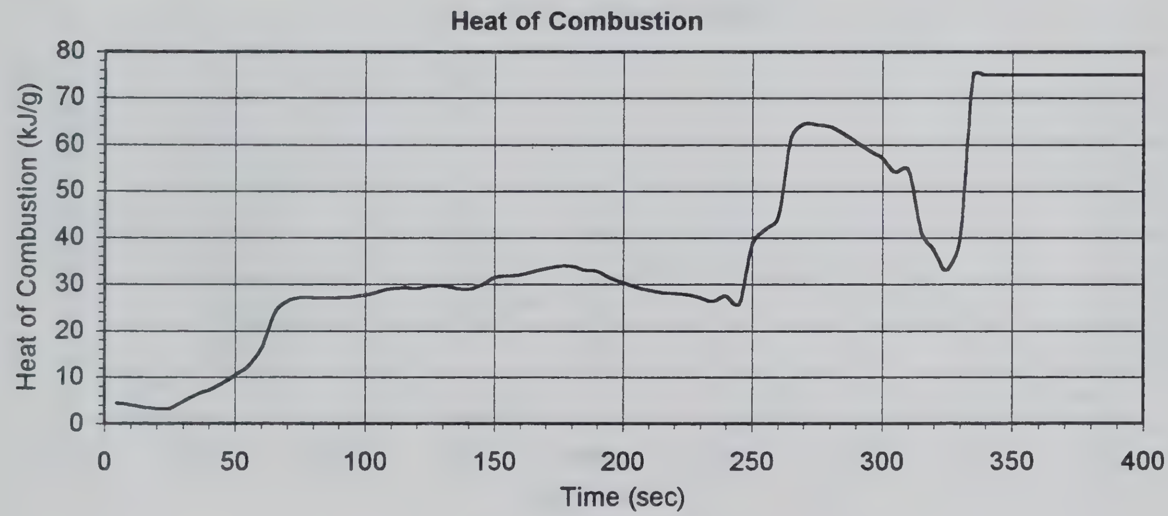


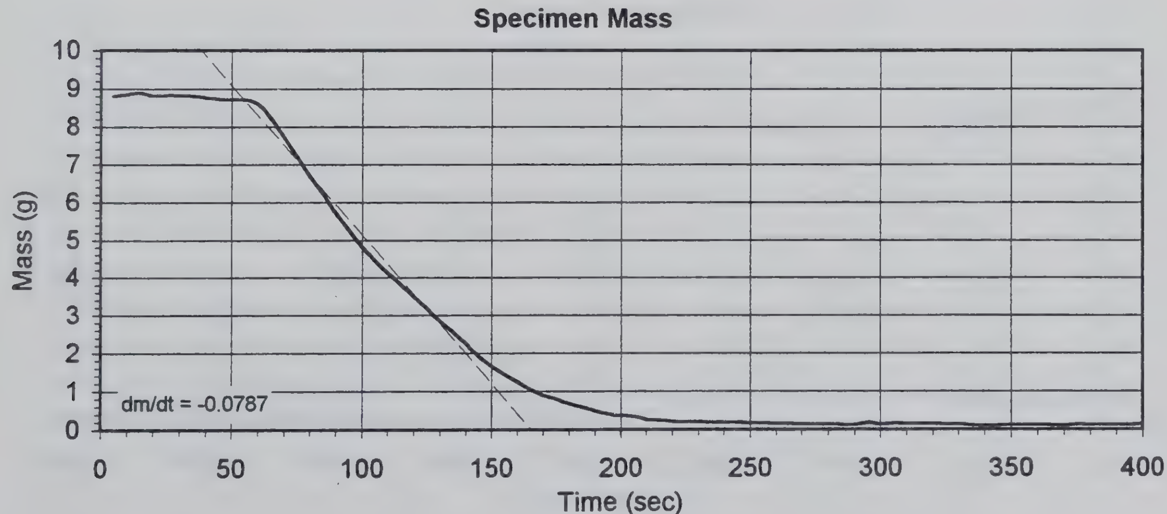




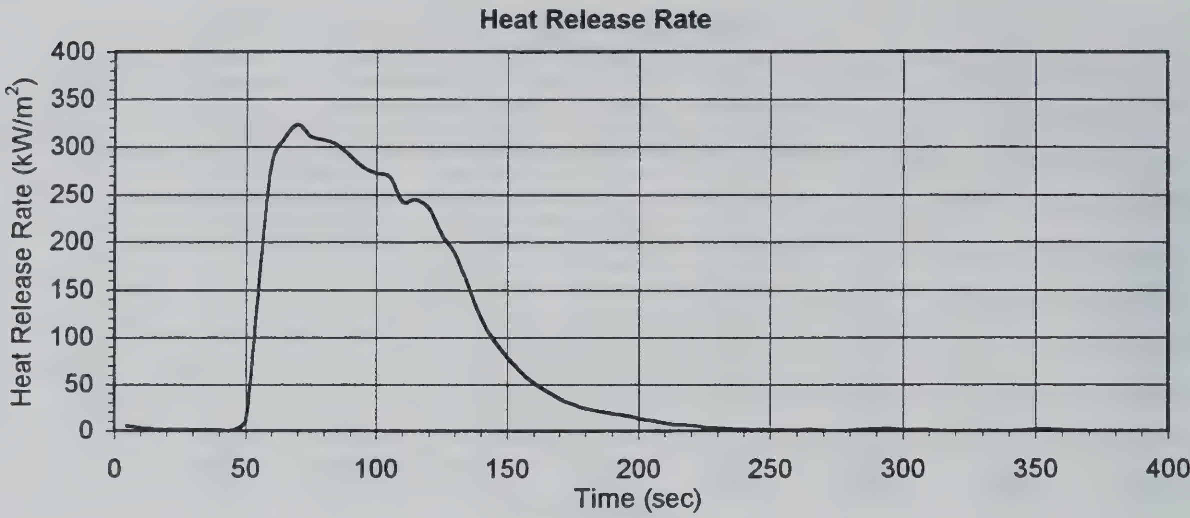
Cone Calorimeter Data R 4.21 F.R. Expanded Polystyrene Board (80 mm)
40 kW/m^2, Test #4

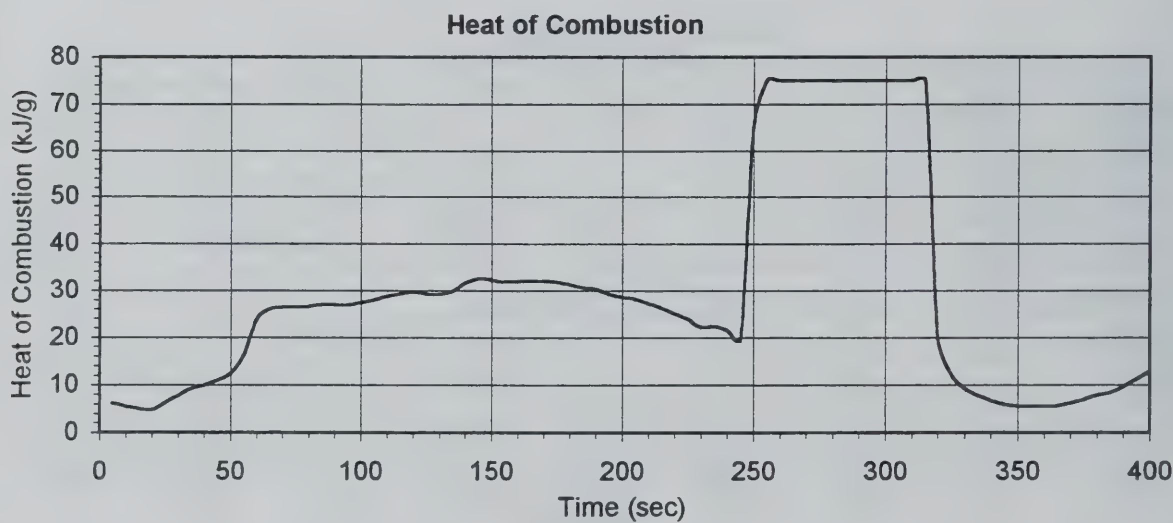


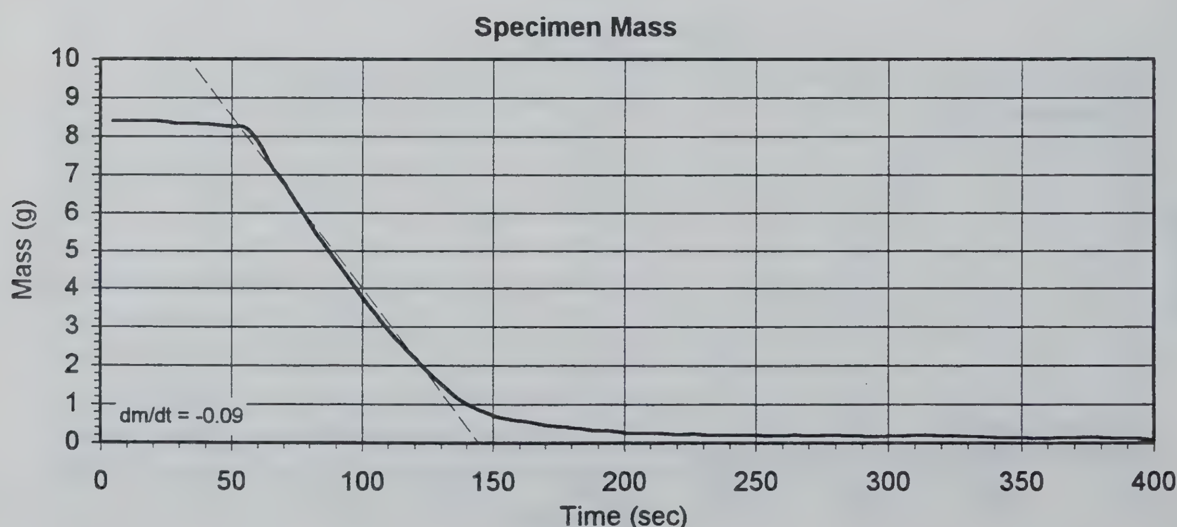




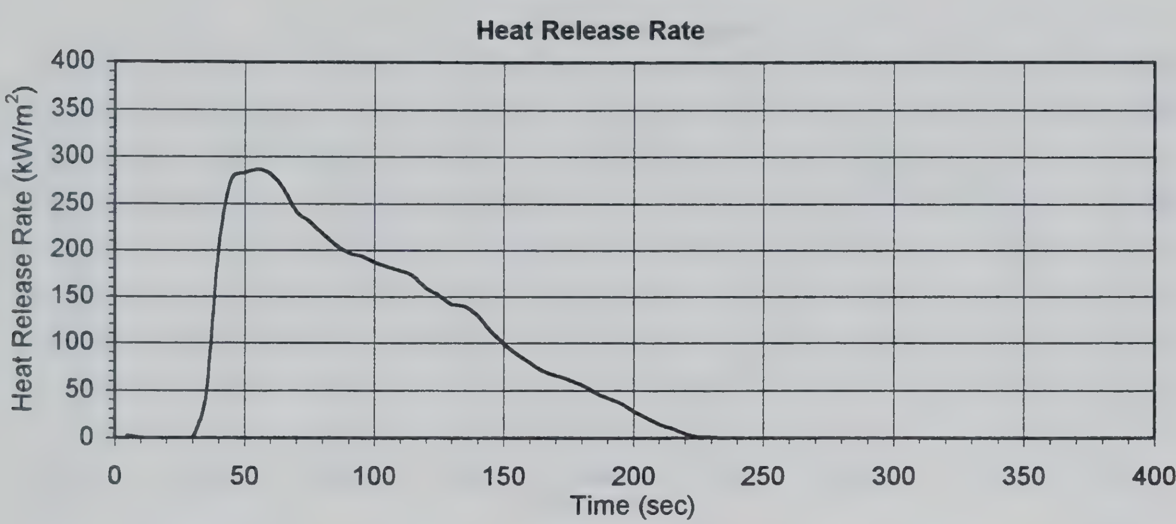
Cone Calorimeter Data R 4.21 F.R. Expanded Polystyrene Board (80 mm)
40 kW/m², Test #5

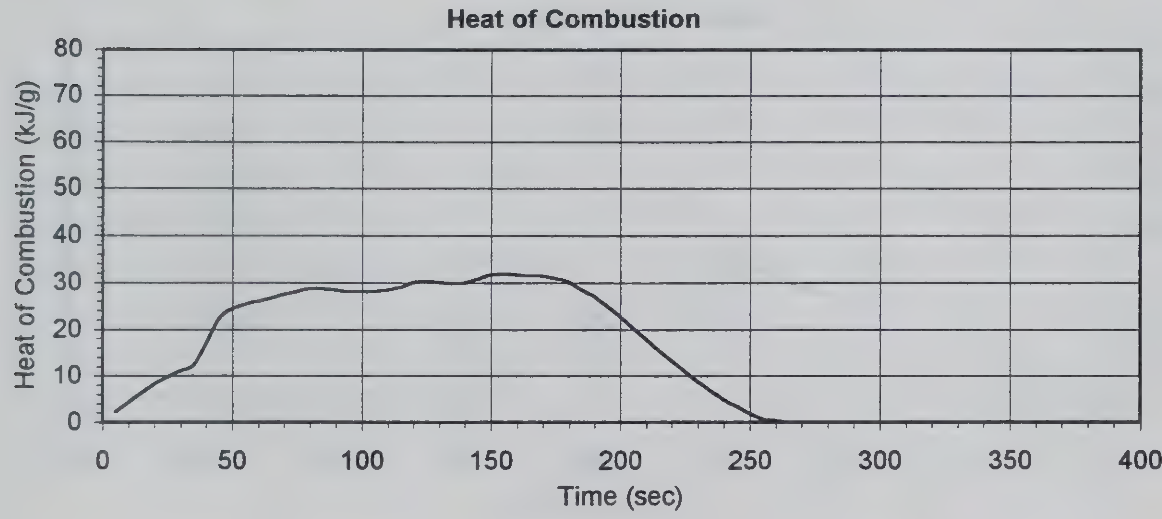


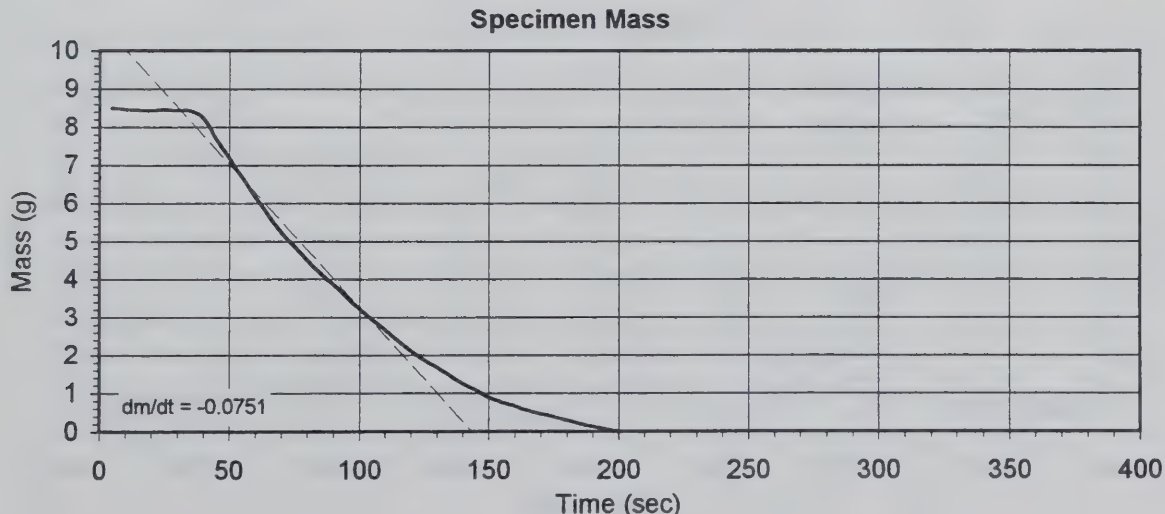




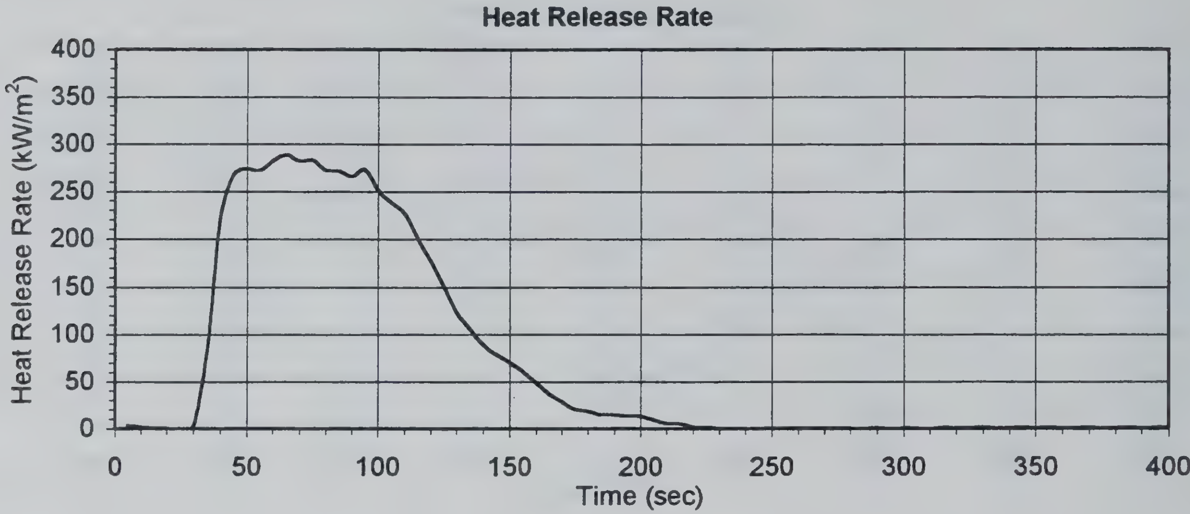
Cone Calorimeter Data R 4.21 F.R. Expanded Polystyrene Board (80 mm)
50 kW/m^2, Test #1

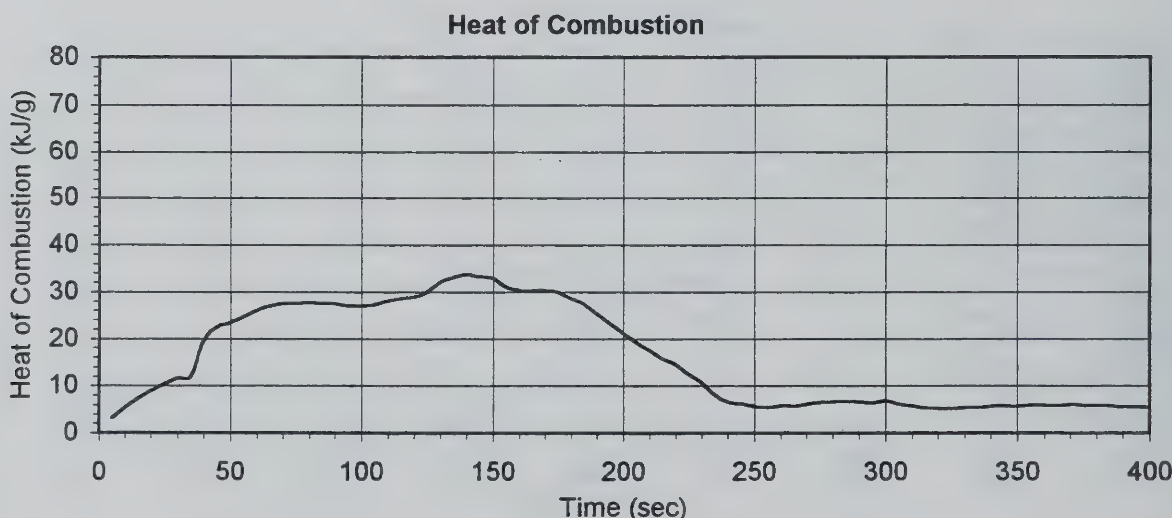


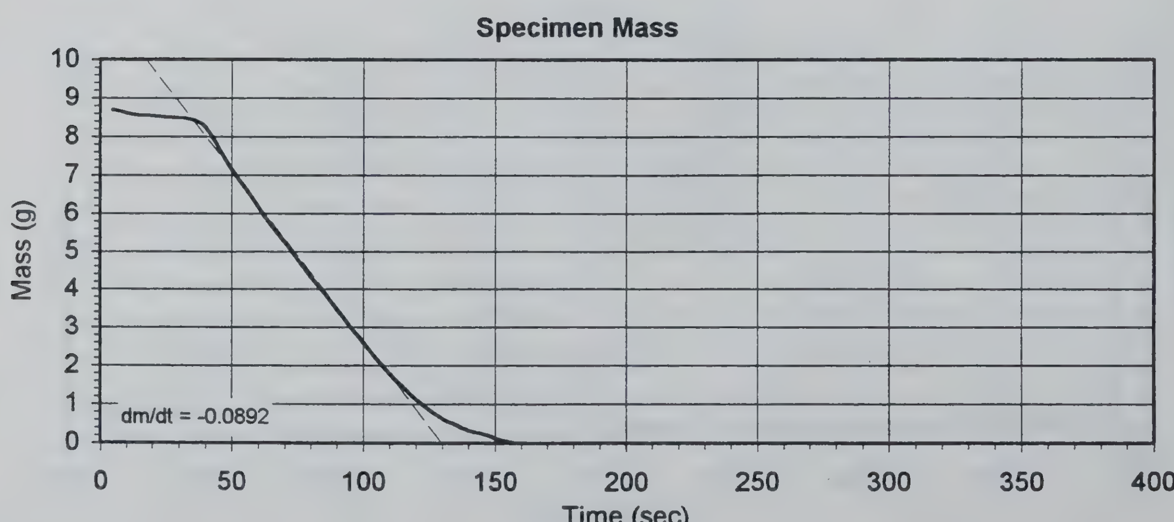




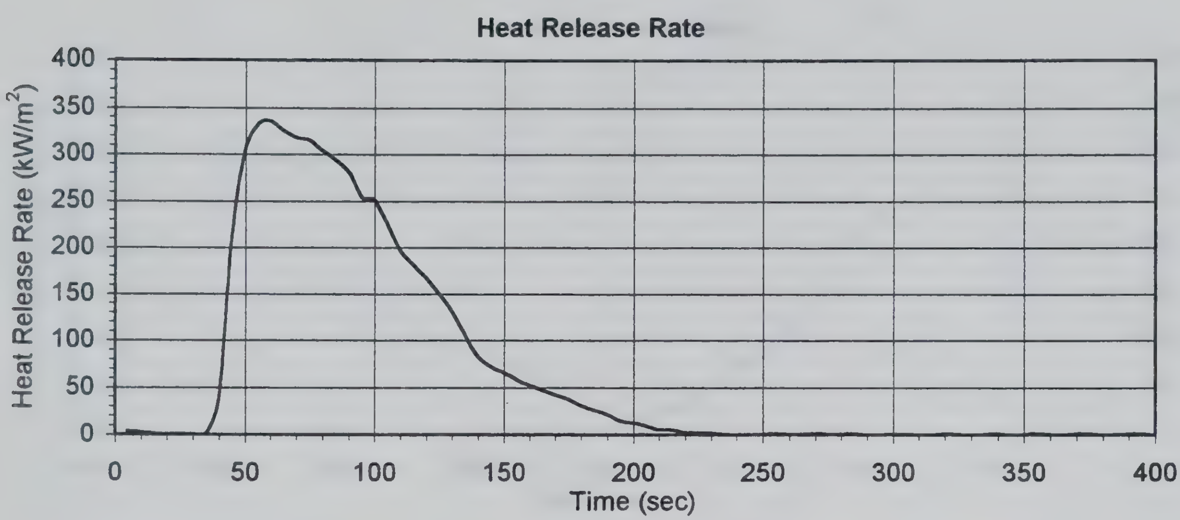
Cone Calorimeter Data R 4.21 F.R. Expanded Polystyrene Board (80 mm)
50 kW/m², Test #2

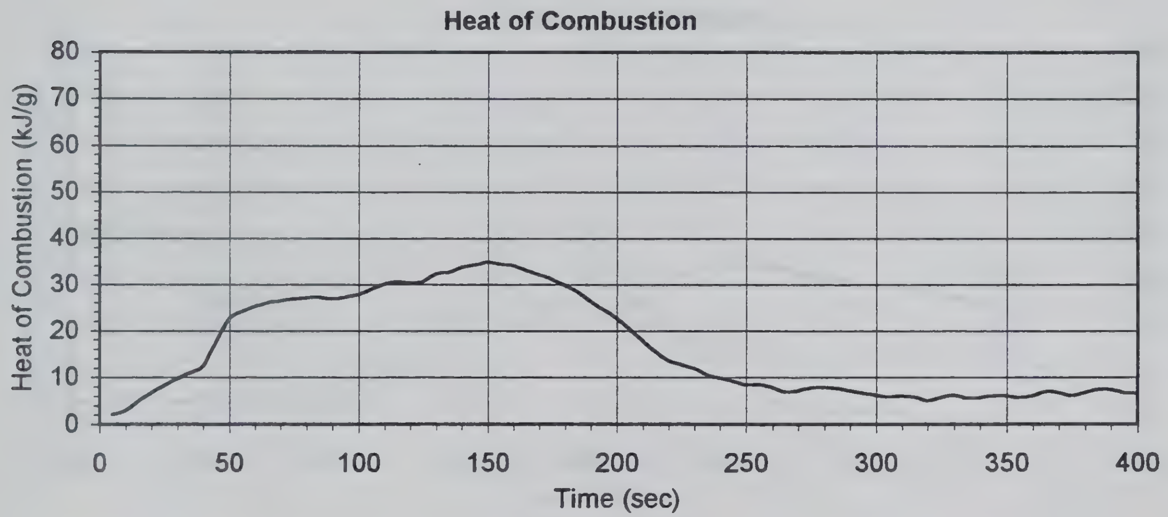


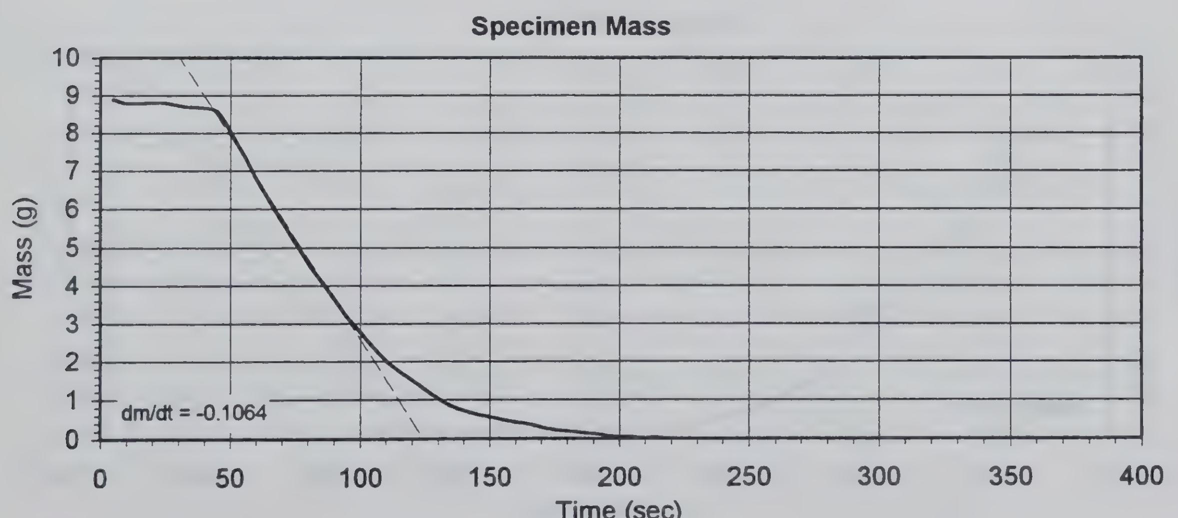




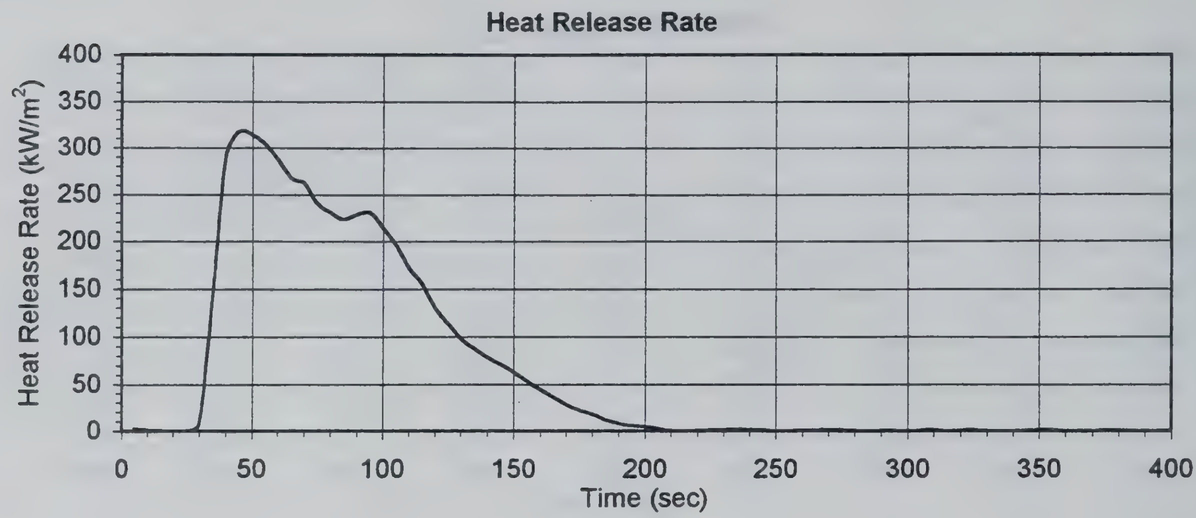
Cone Calorimeter Data R 4.21 F.R. Expanded Polystyrene Board (80 mm)
50 kW/m², Test #3

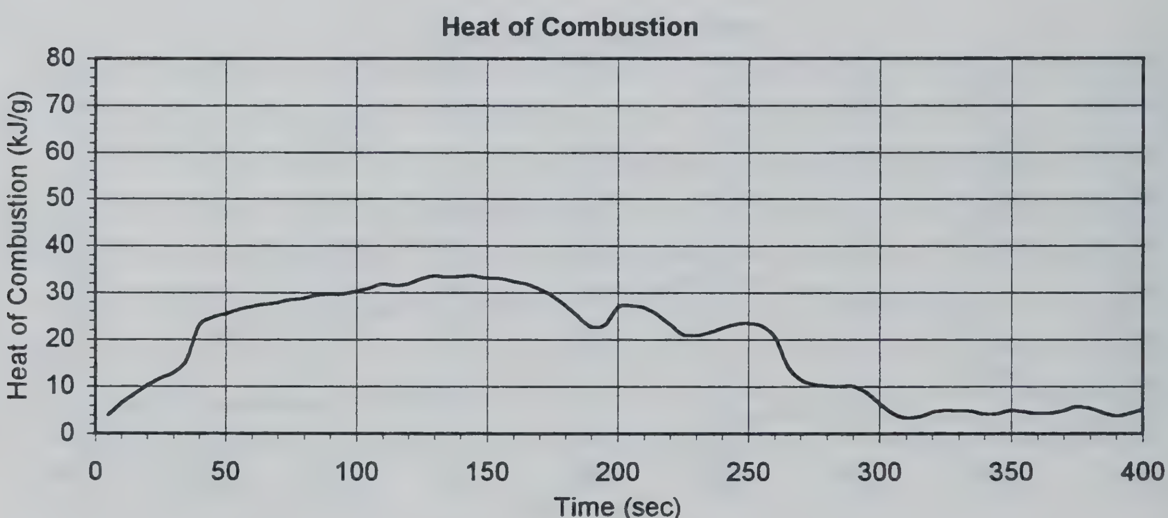


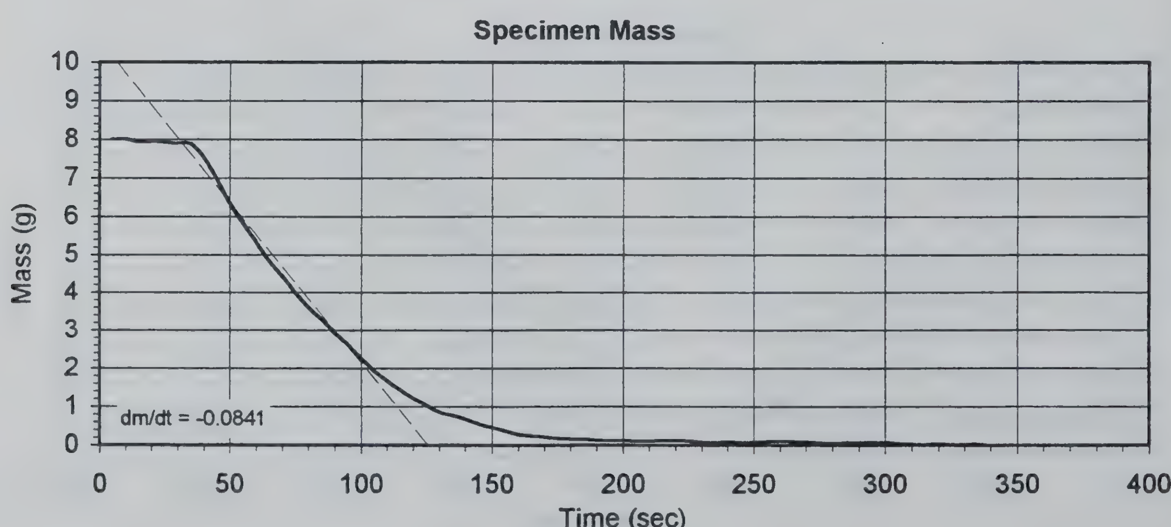




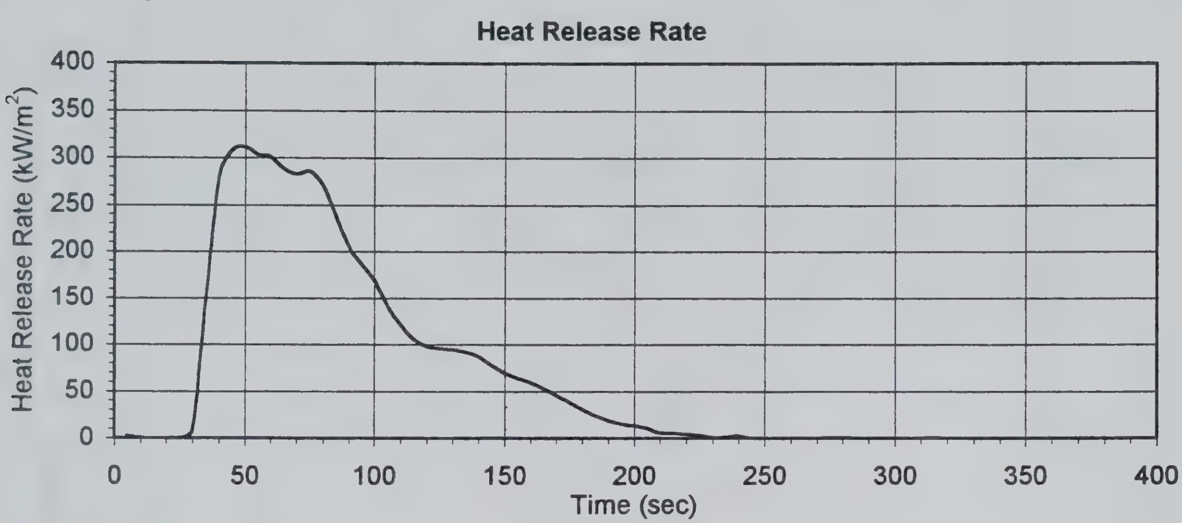
Cone Calorimeter Data R 4.21 F.R. Expanded Polystyrene Board (80 mm)
50 kW/m², Test #4

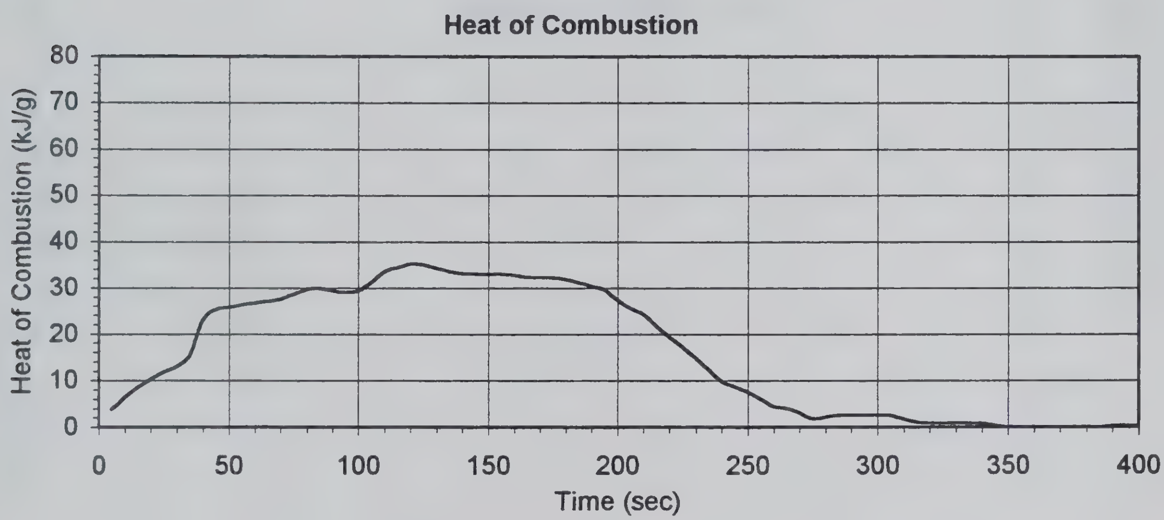


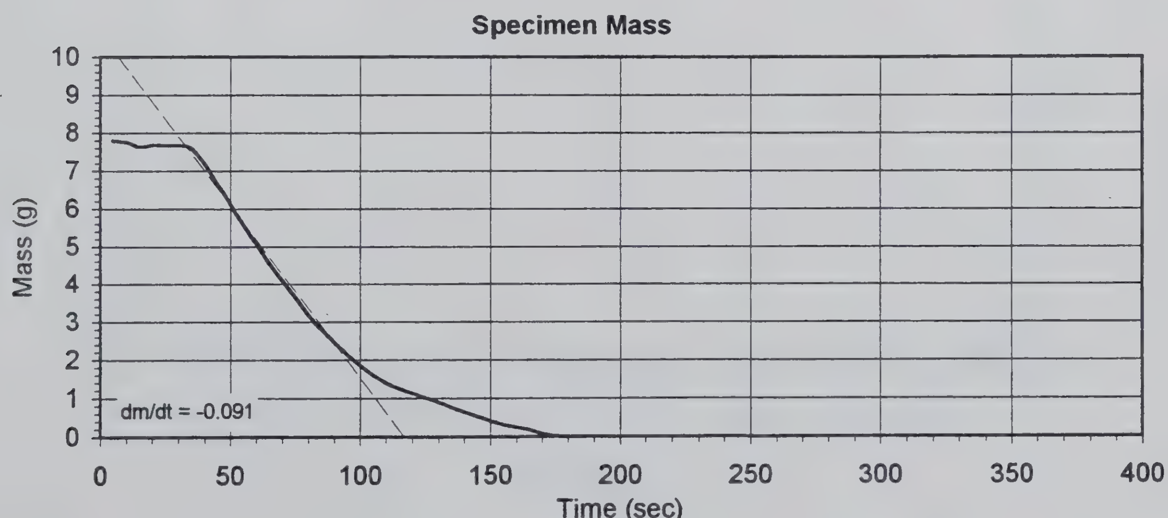




Cone Calorimeter Data R 4.21 F.R. Expanded Polystyrene Board (80 mm)
50 kW/m^2, Test #5

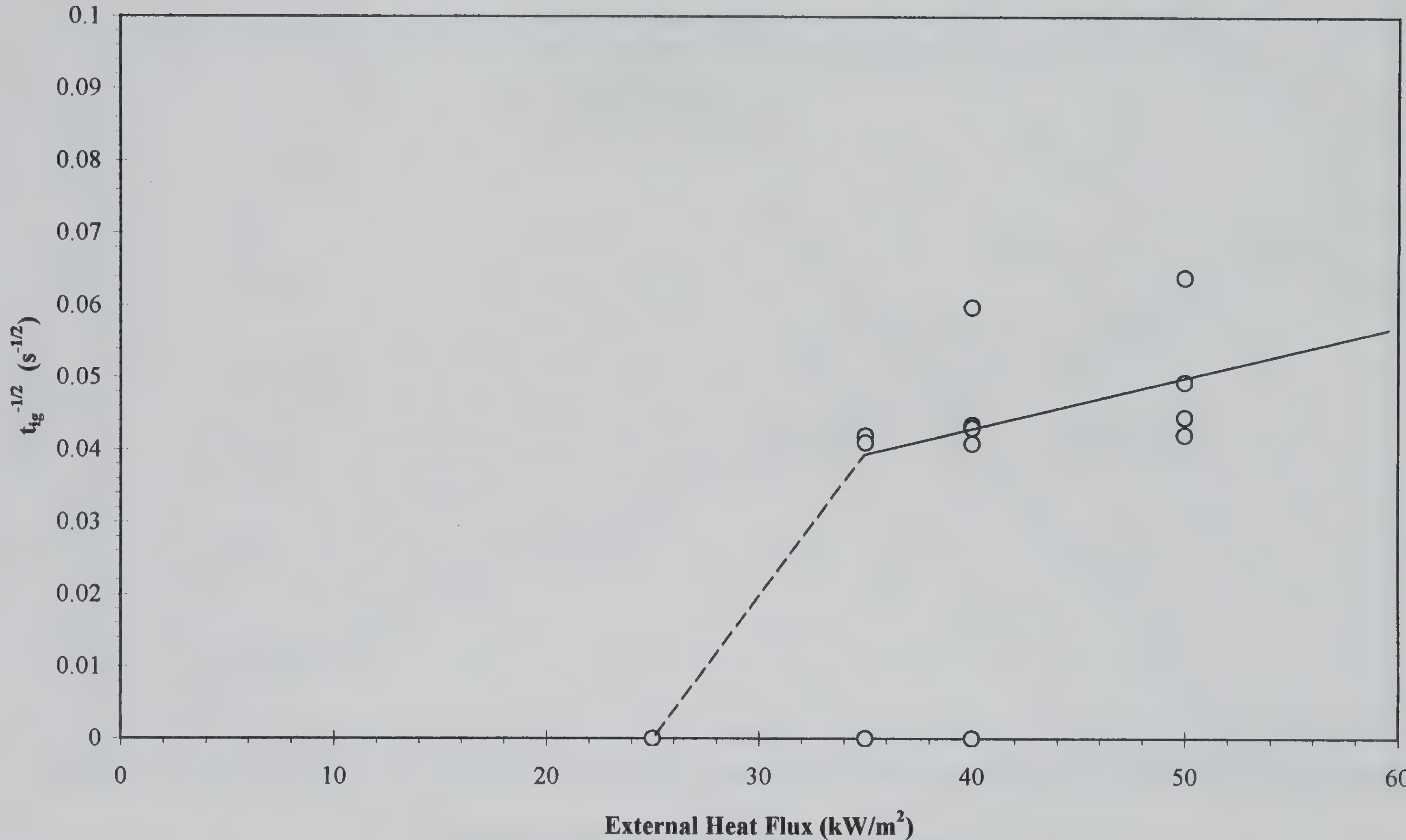




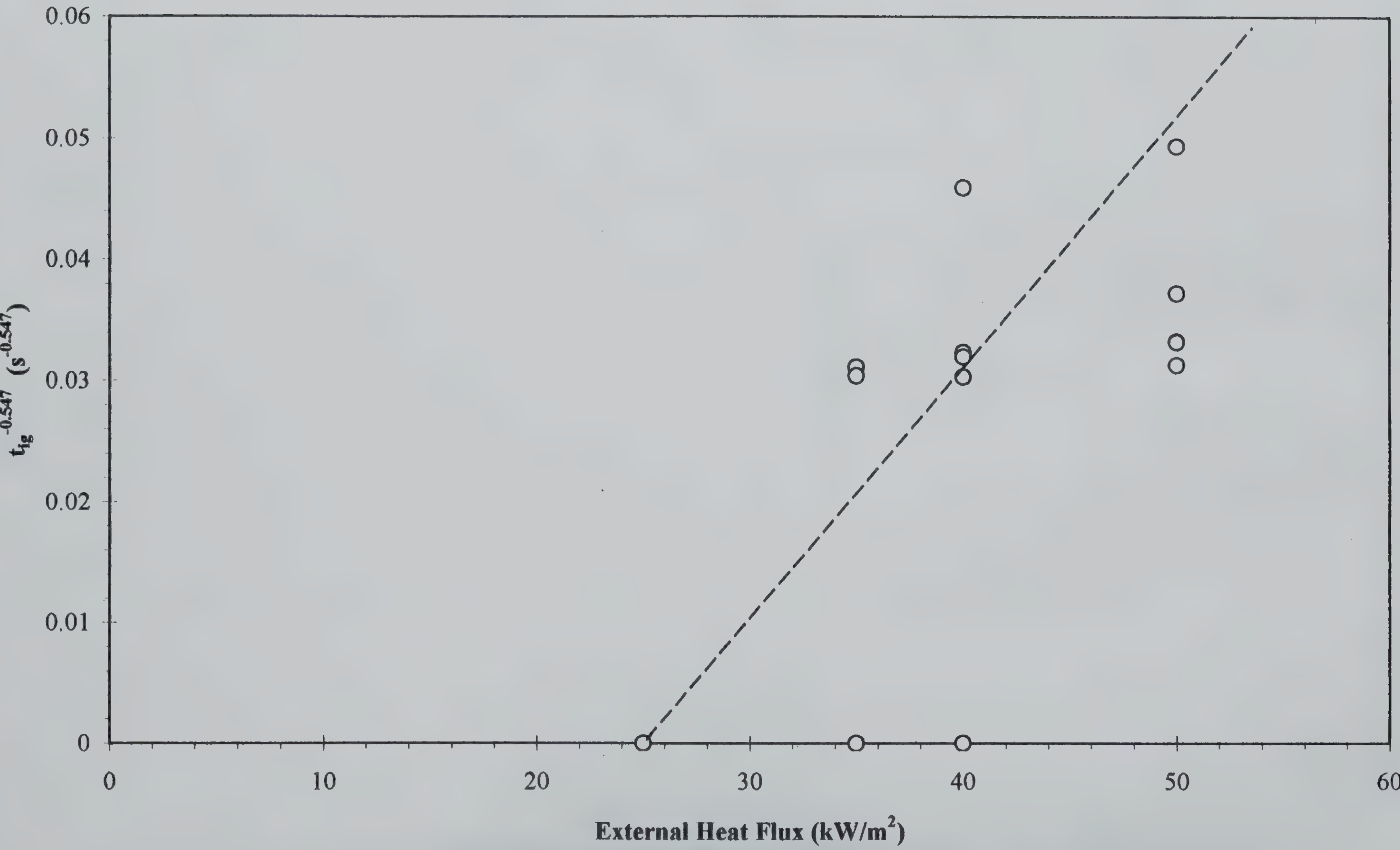


A.3 – Ignition Data

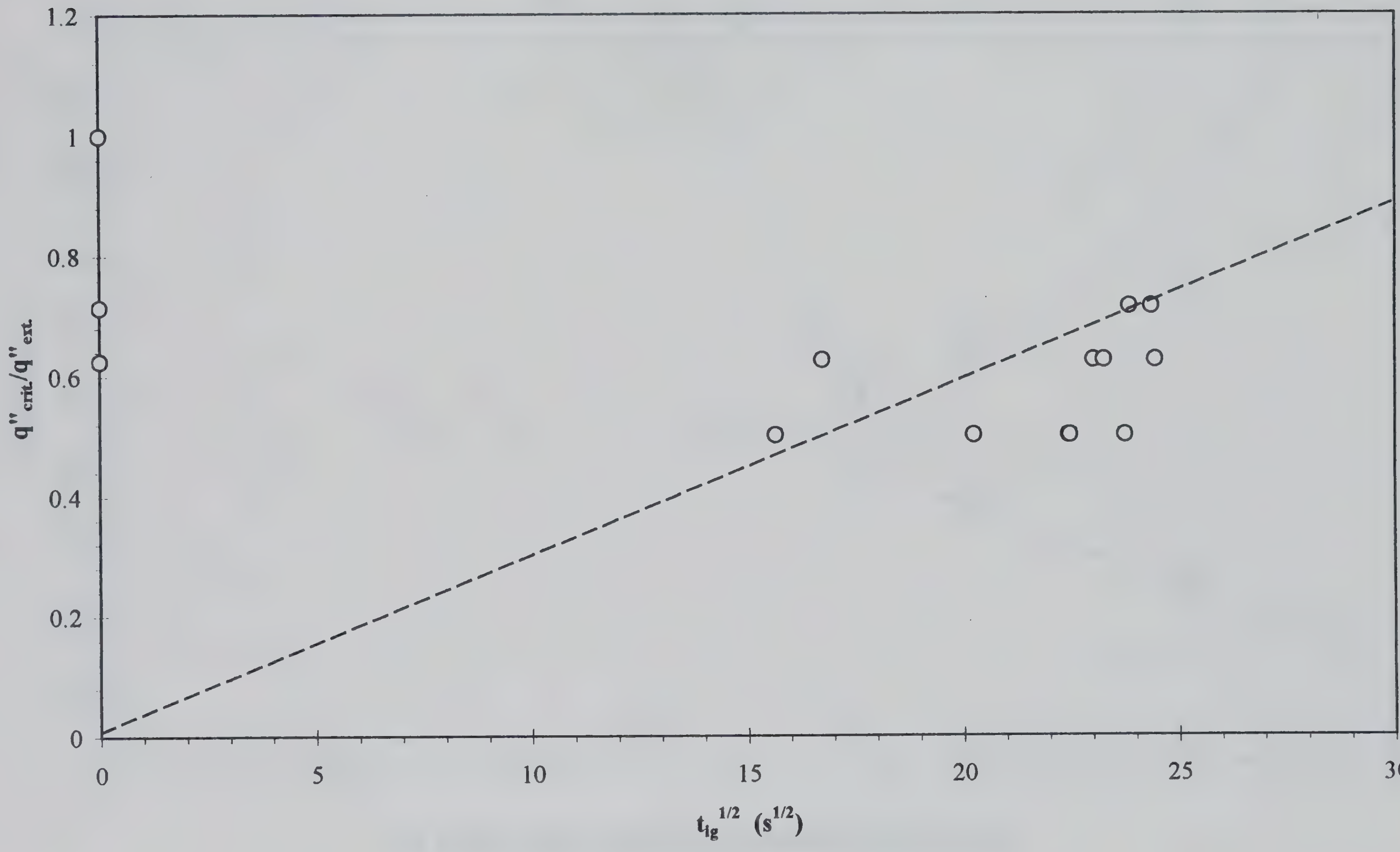
R 4.01: Fire Retarded Chipboard



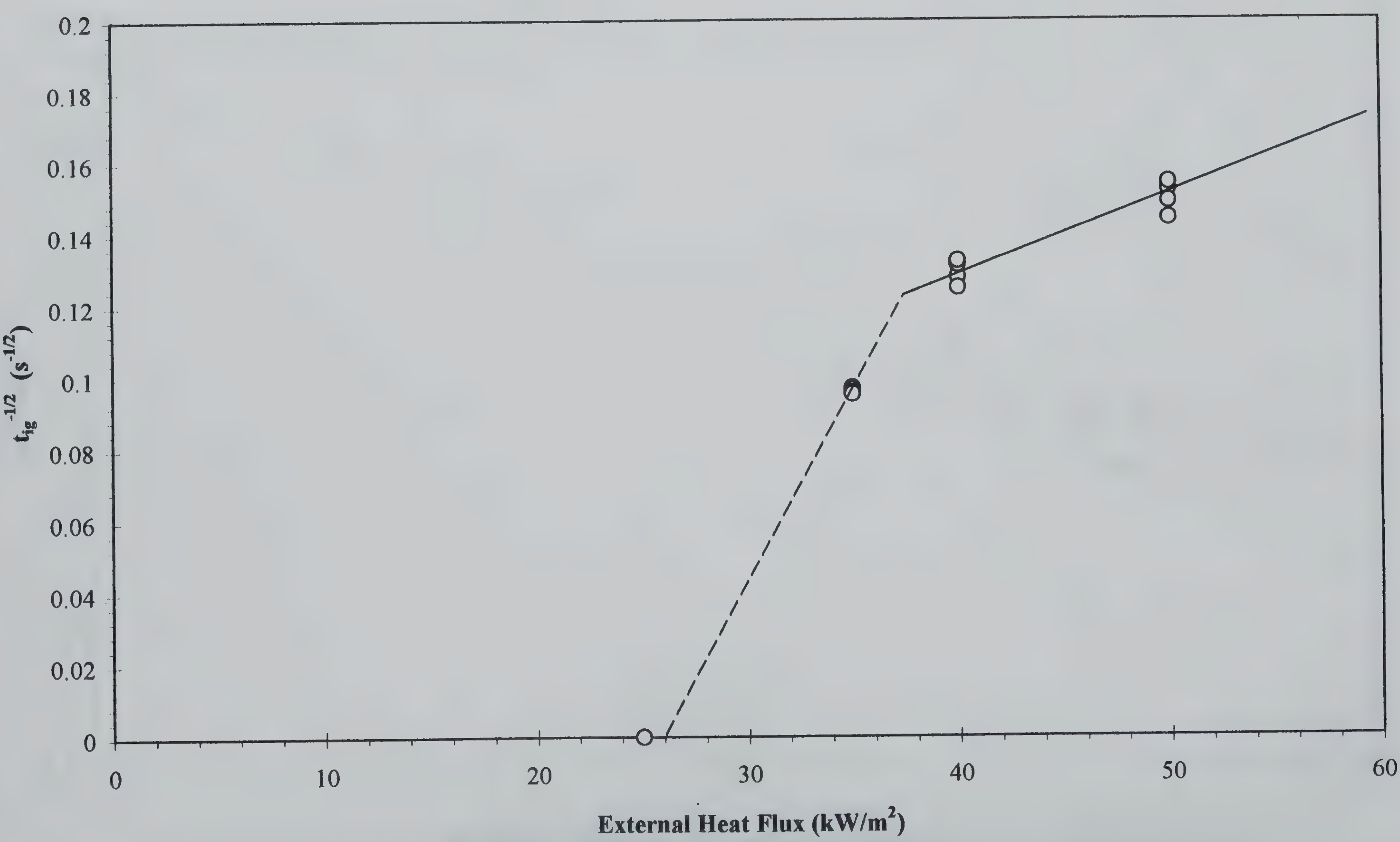
R 4.01: Fire Retarded Chipboard



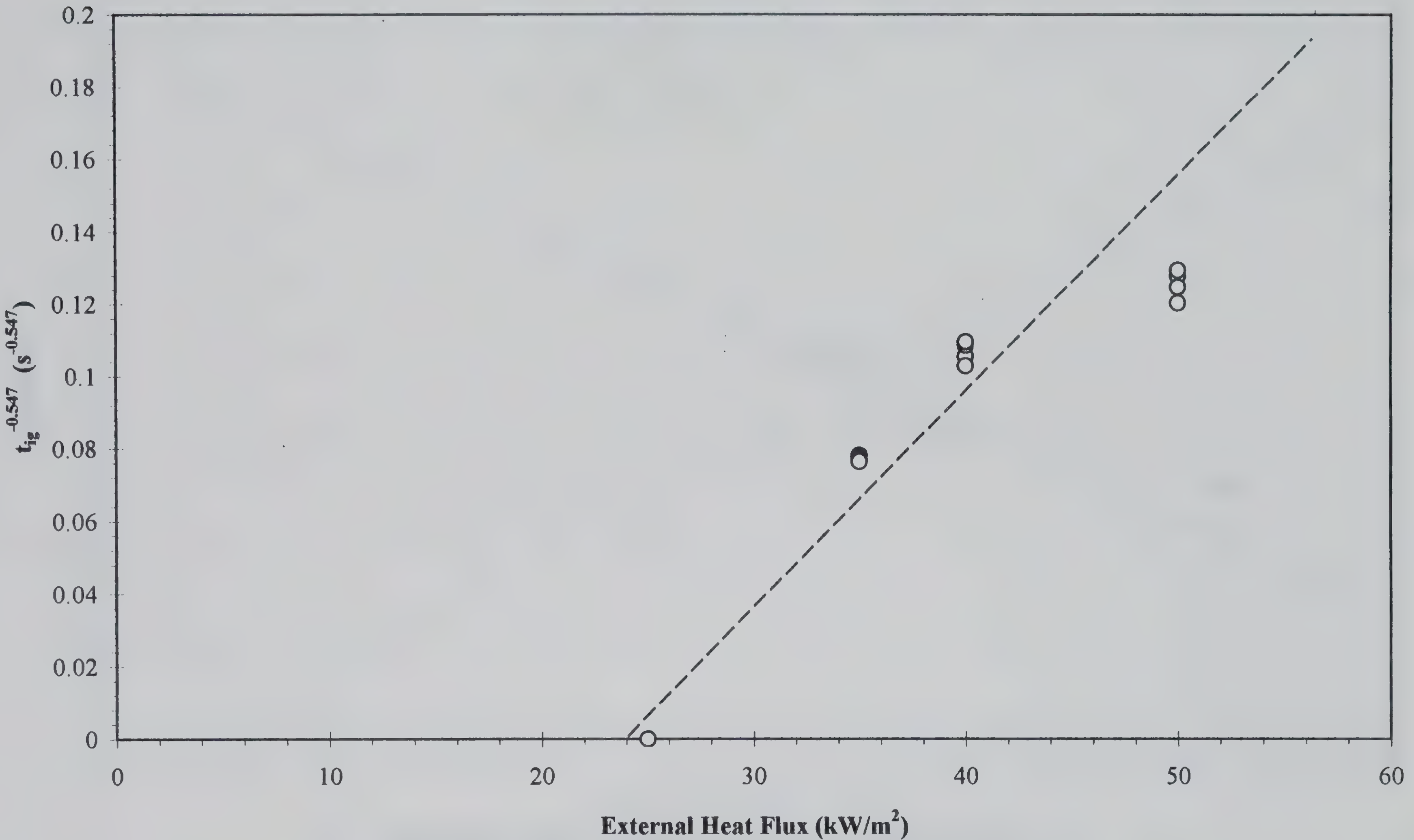
R 4.01: Fire Retarded Chipboard



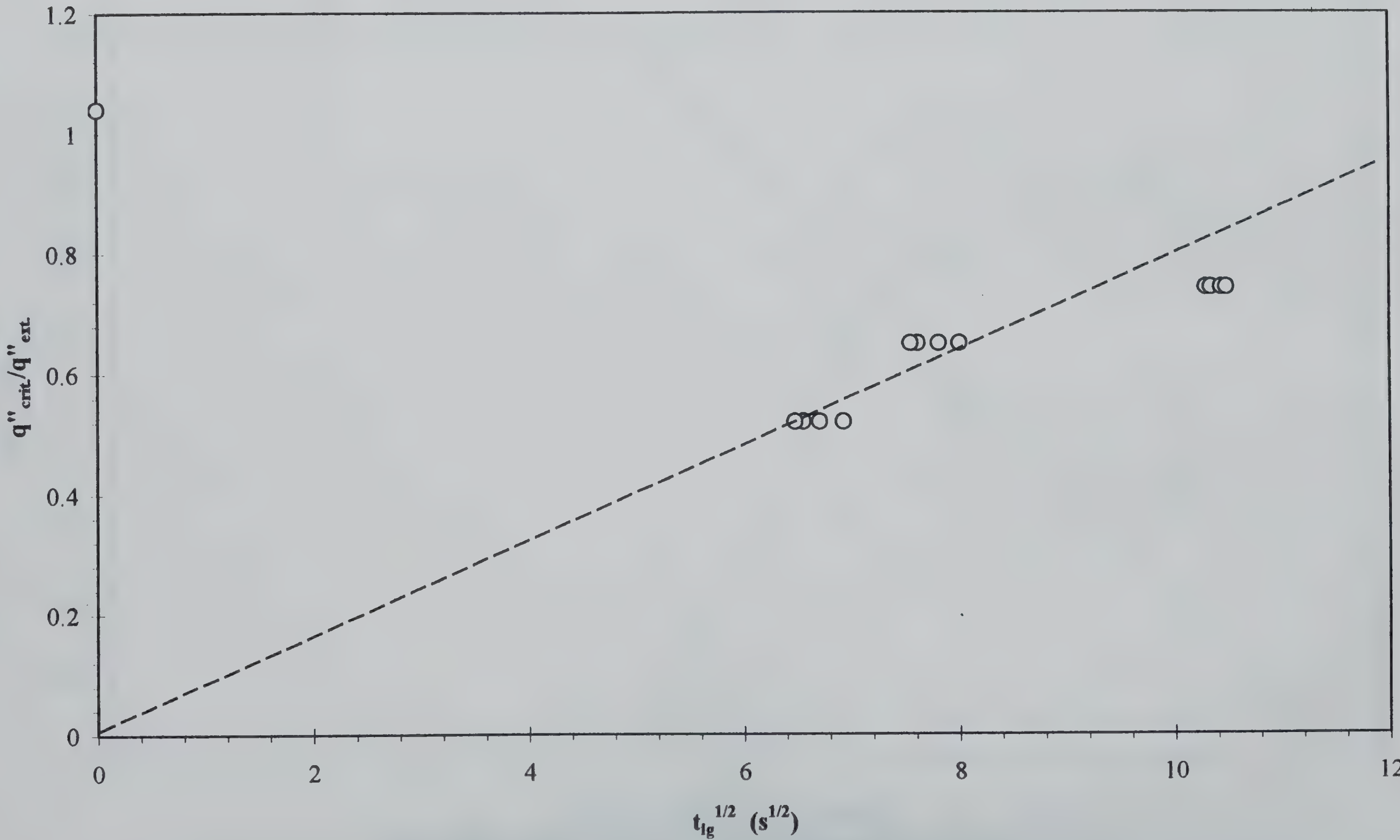
R 4.02: Paper Faced Gypsum Wallboard



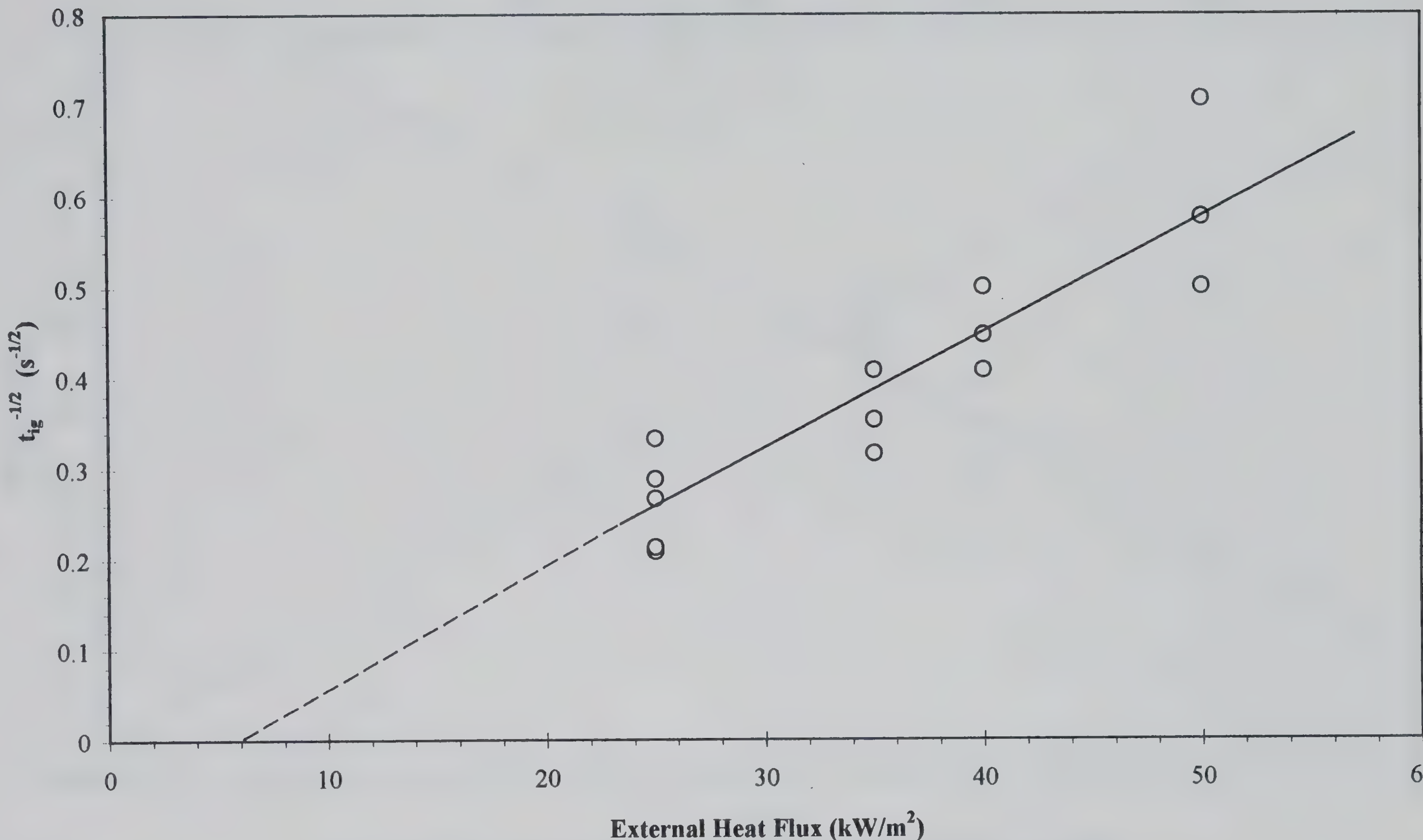
R 4.02: Paper Faced Gypsum Wallboard



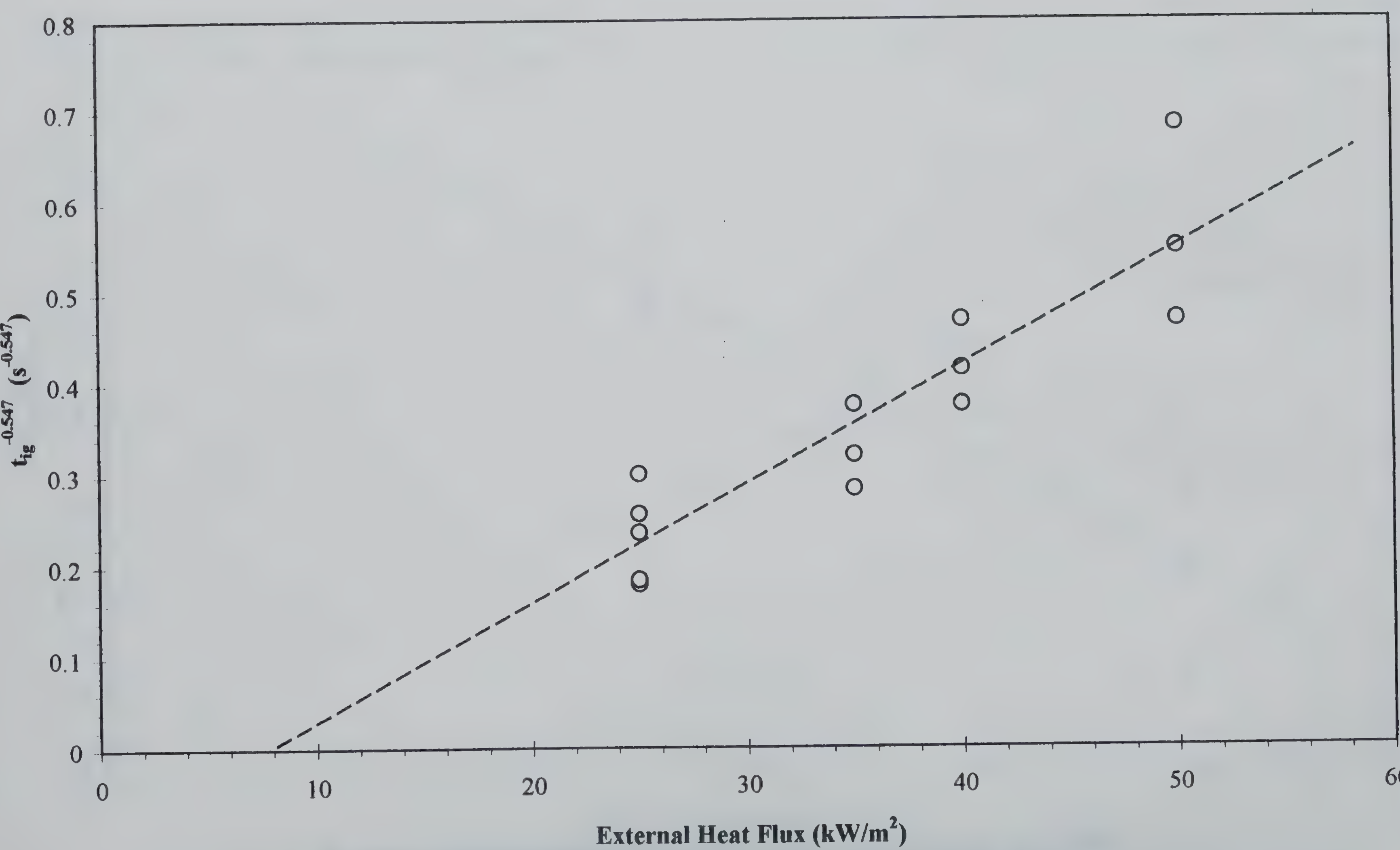
R 4.02: Paper Faced Gypsum Wallboard



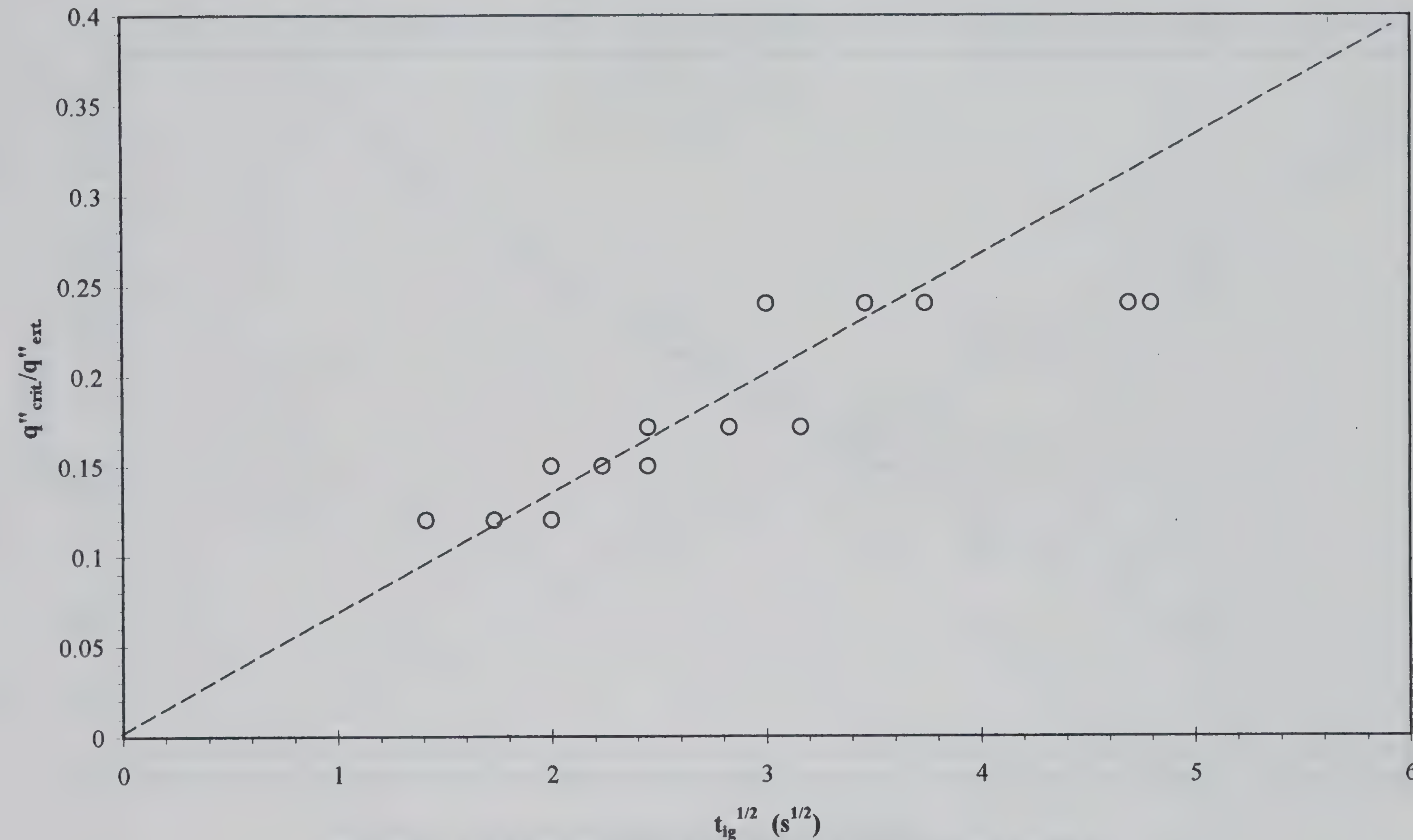
R 4.04: Polyurethane Foam Panel with Paper Facing



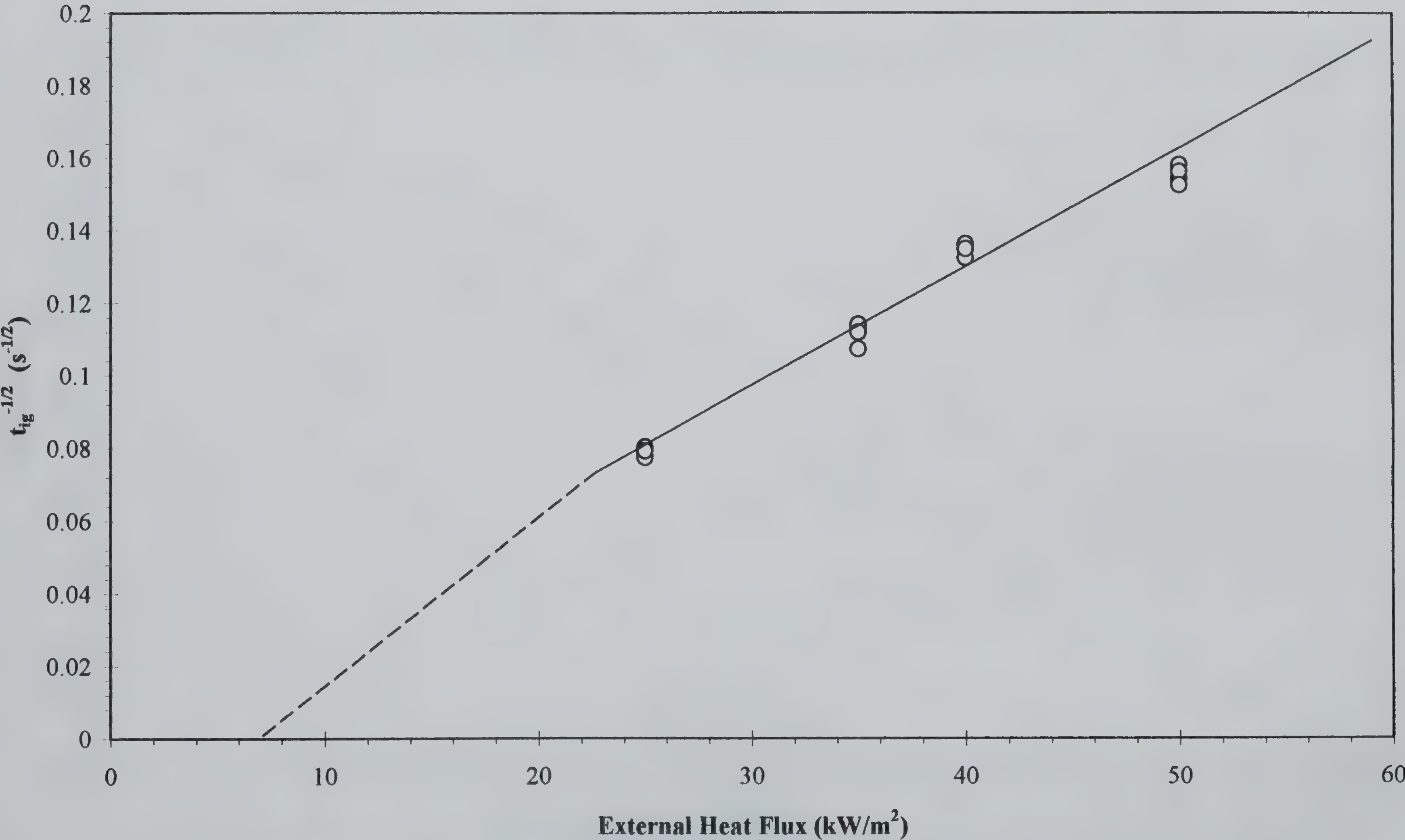
R 4.04: Polyurethane Foam Panel with Paper Facing



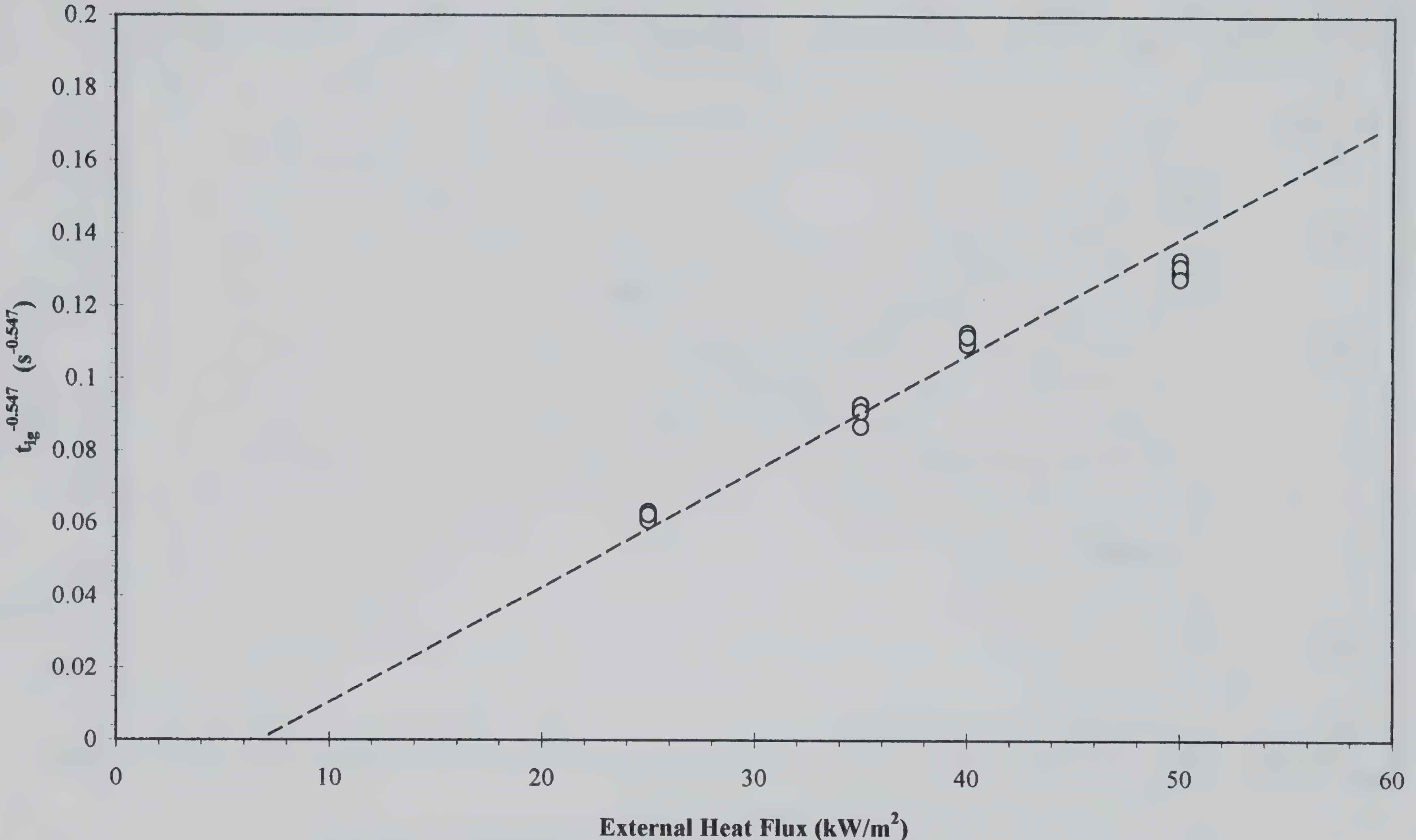
R 4.04: Polyurethane Foam Panel with Paper Facing



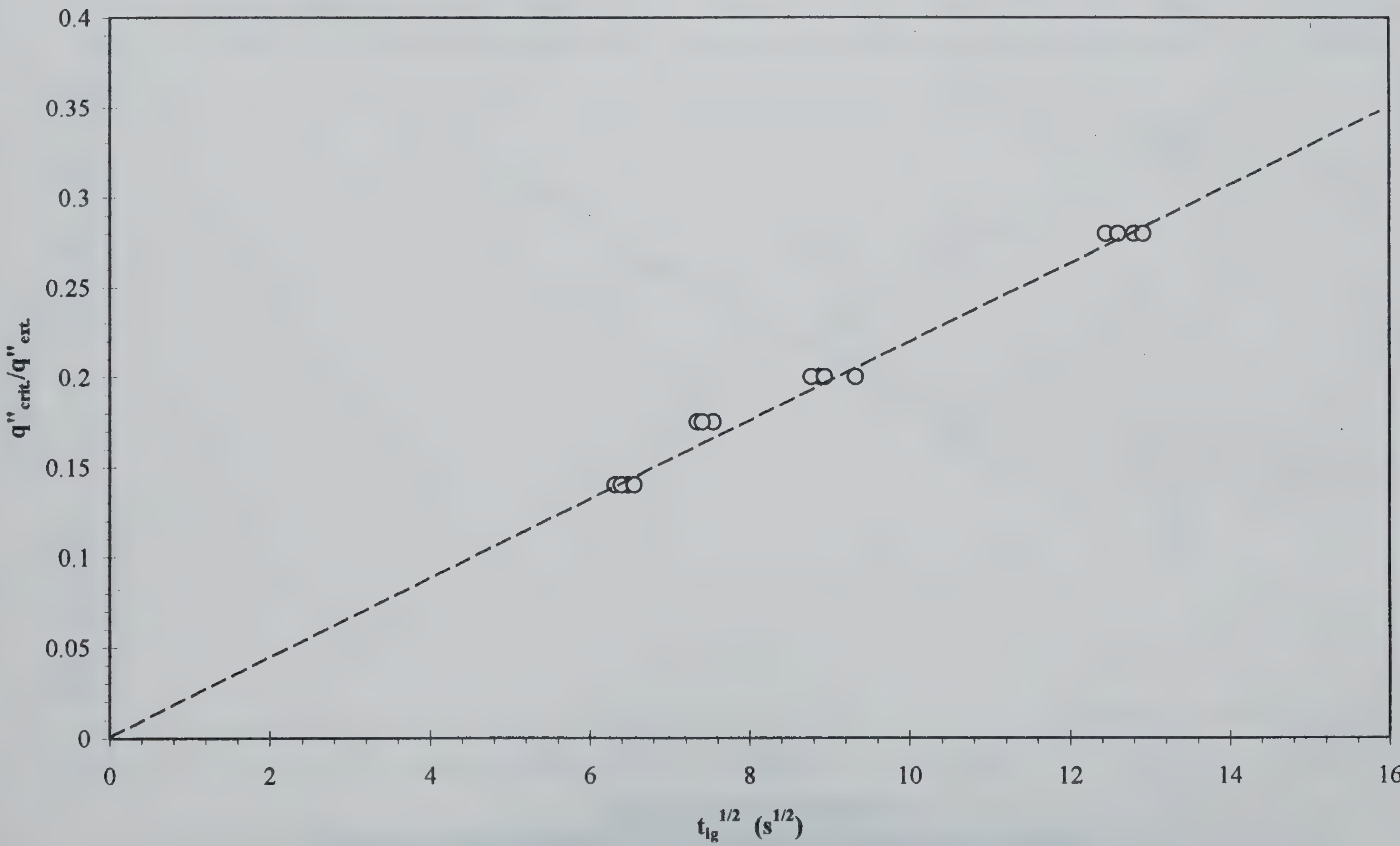
R 4.05: Fire Retarded, Extruded Polystyrene Board



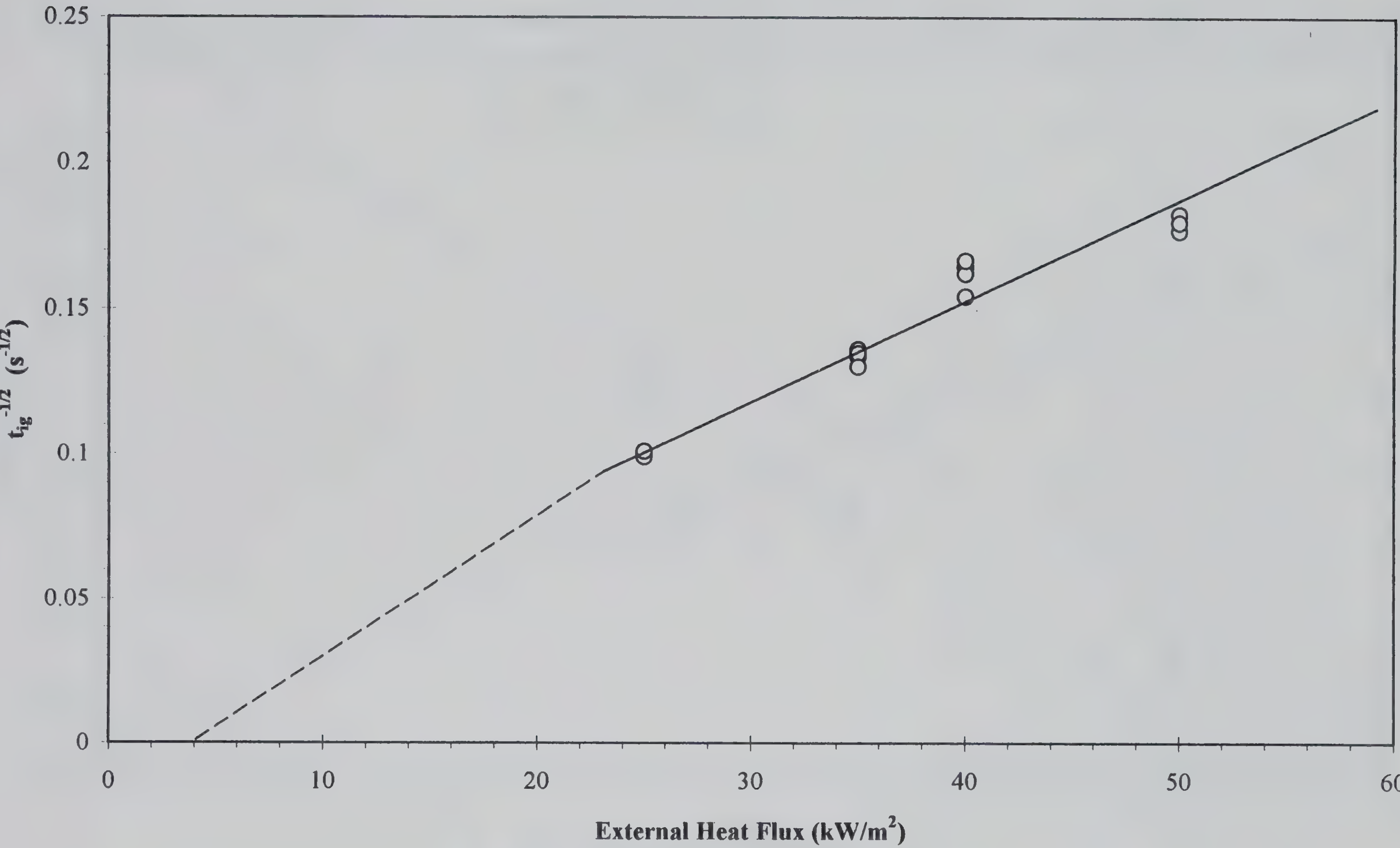
R 4.05: Fire Retarded, Extruded Polystyrene Board



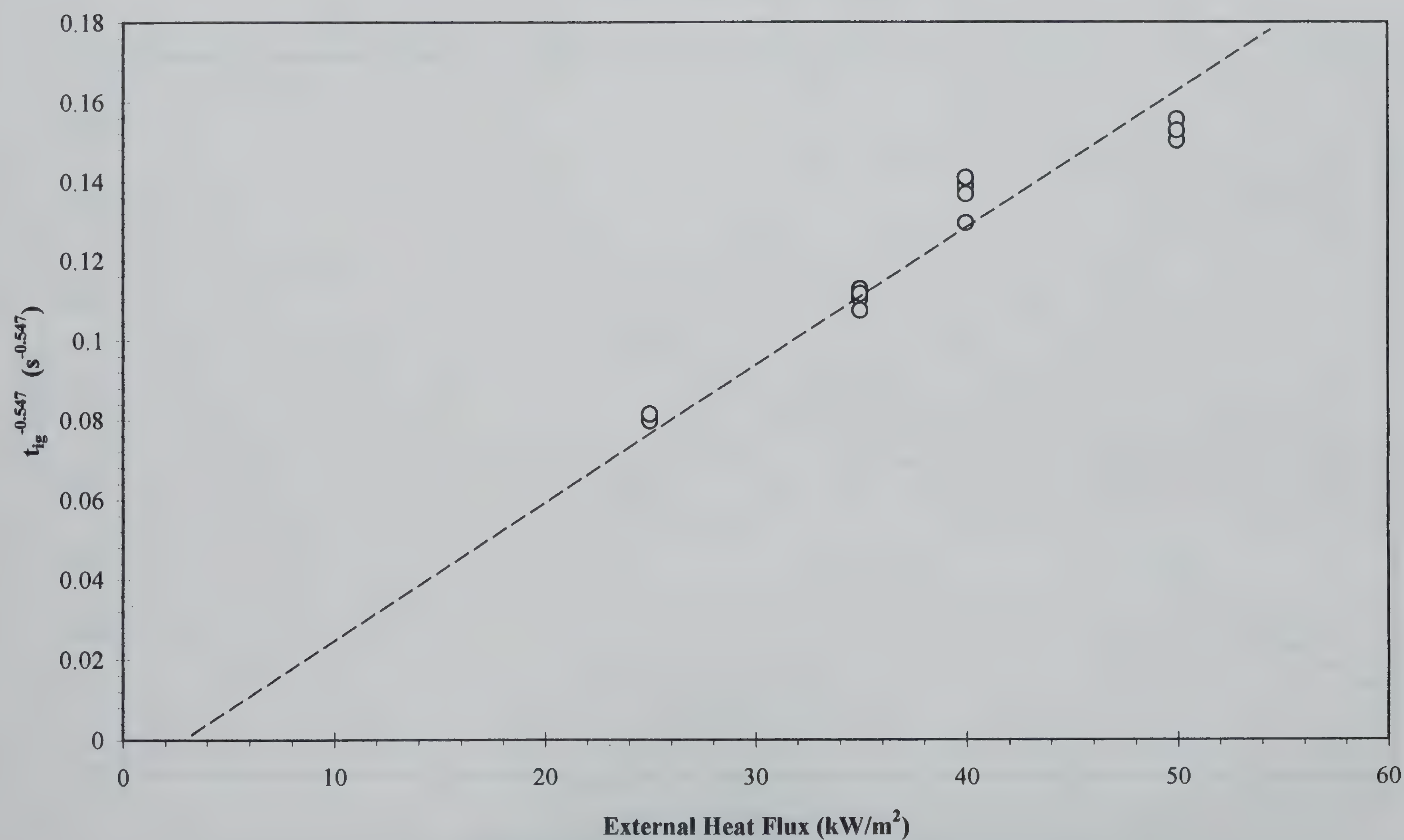
R 4.05: Fire Retarded, Extruded Polystyrene Board



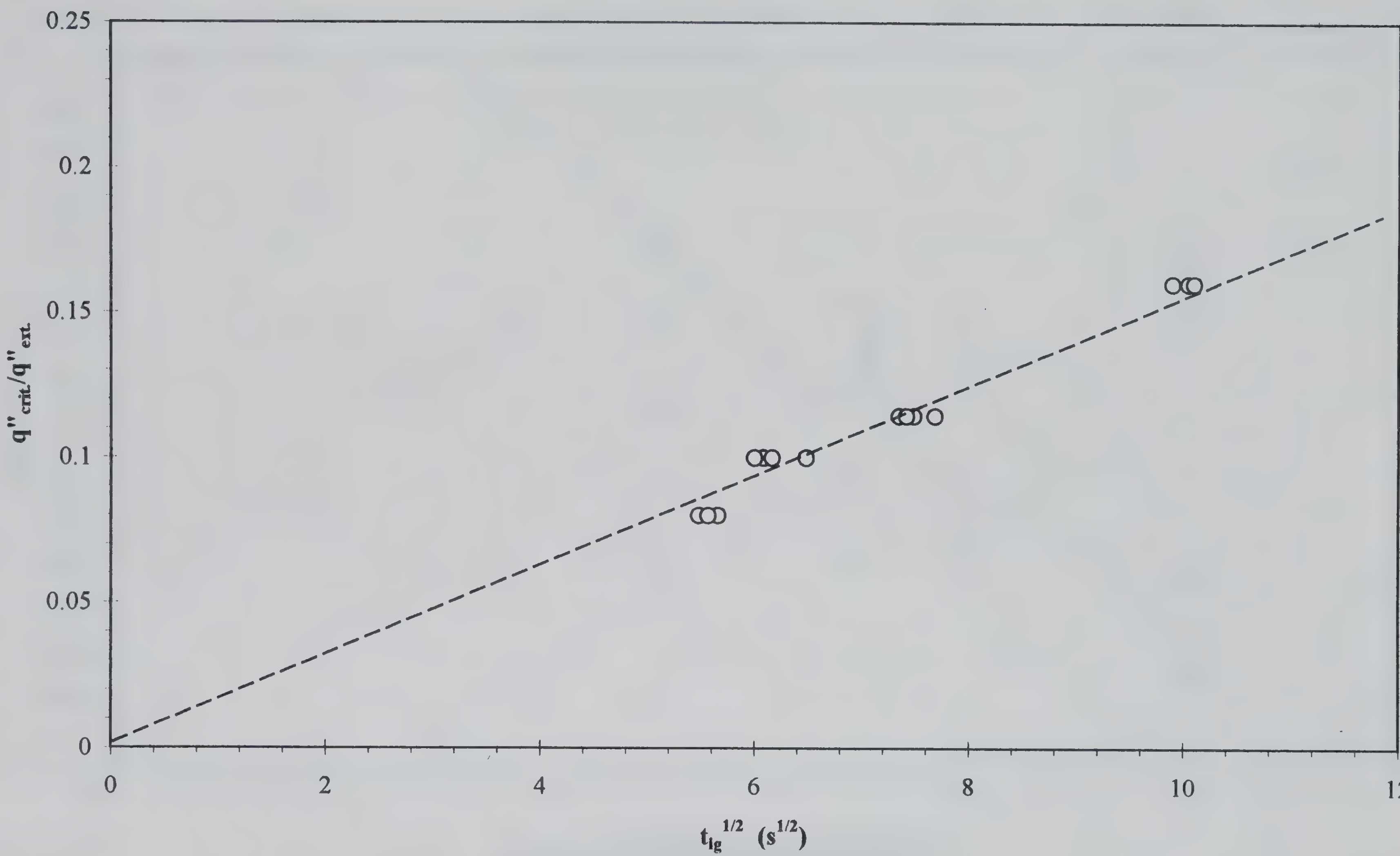
R 4.06: Clear Acrylic Glazing



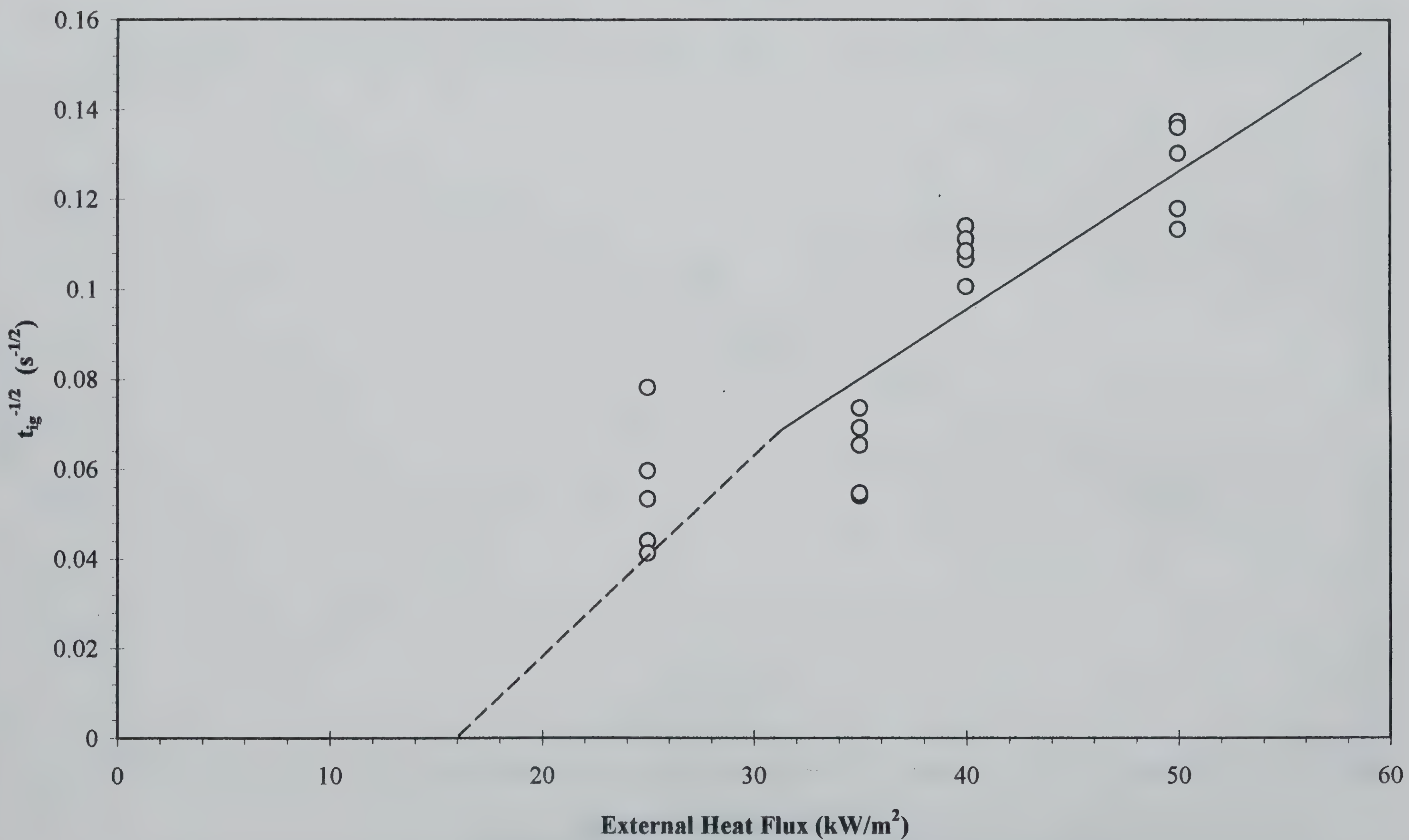
R 4.06: Clear Acrylic Glazing



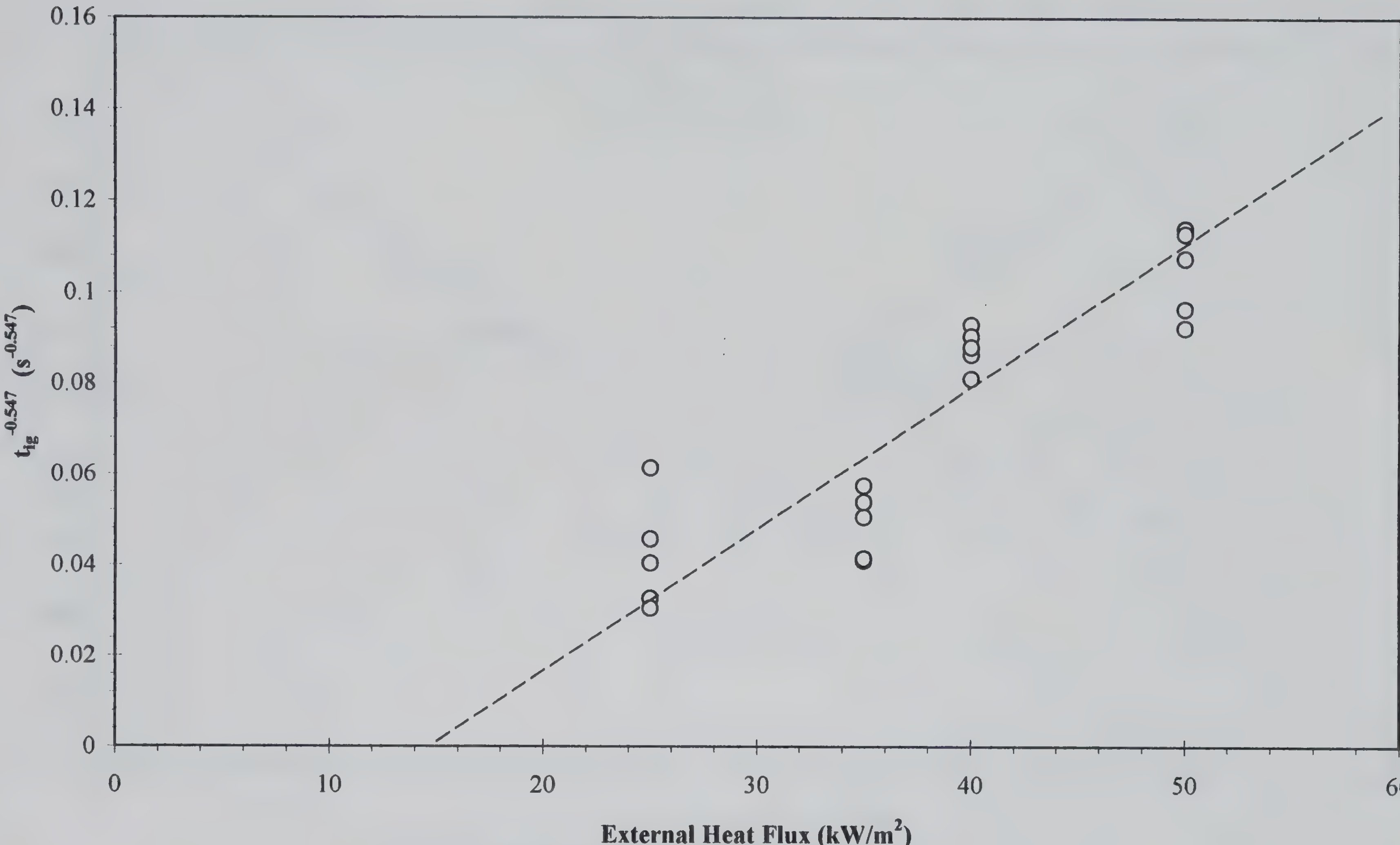
R 4.06: Clear Acrylic Glazing



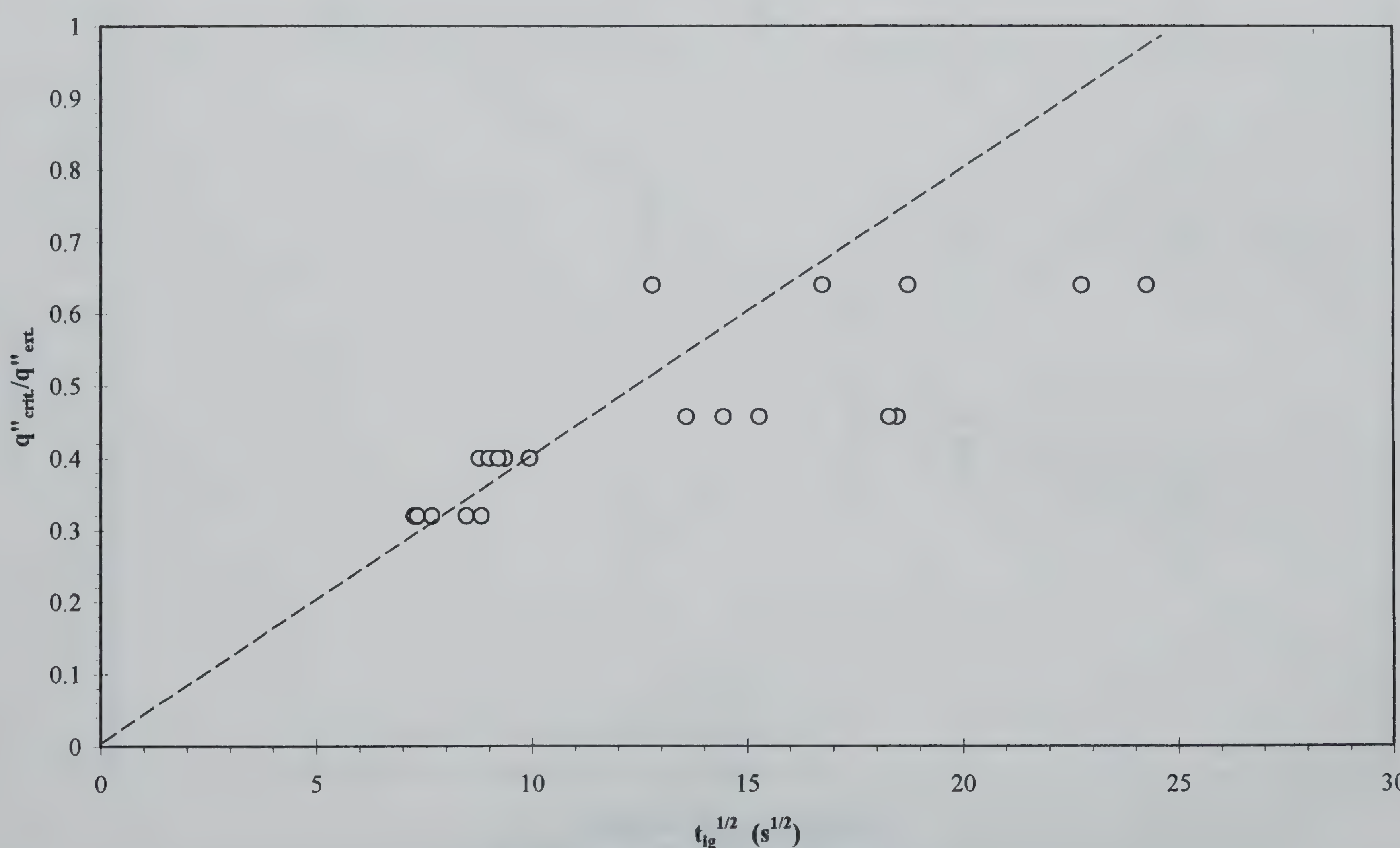
R 4.07: Fire Retarded PVC



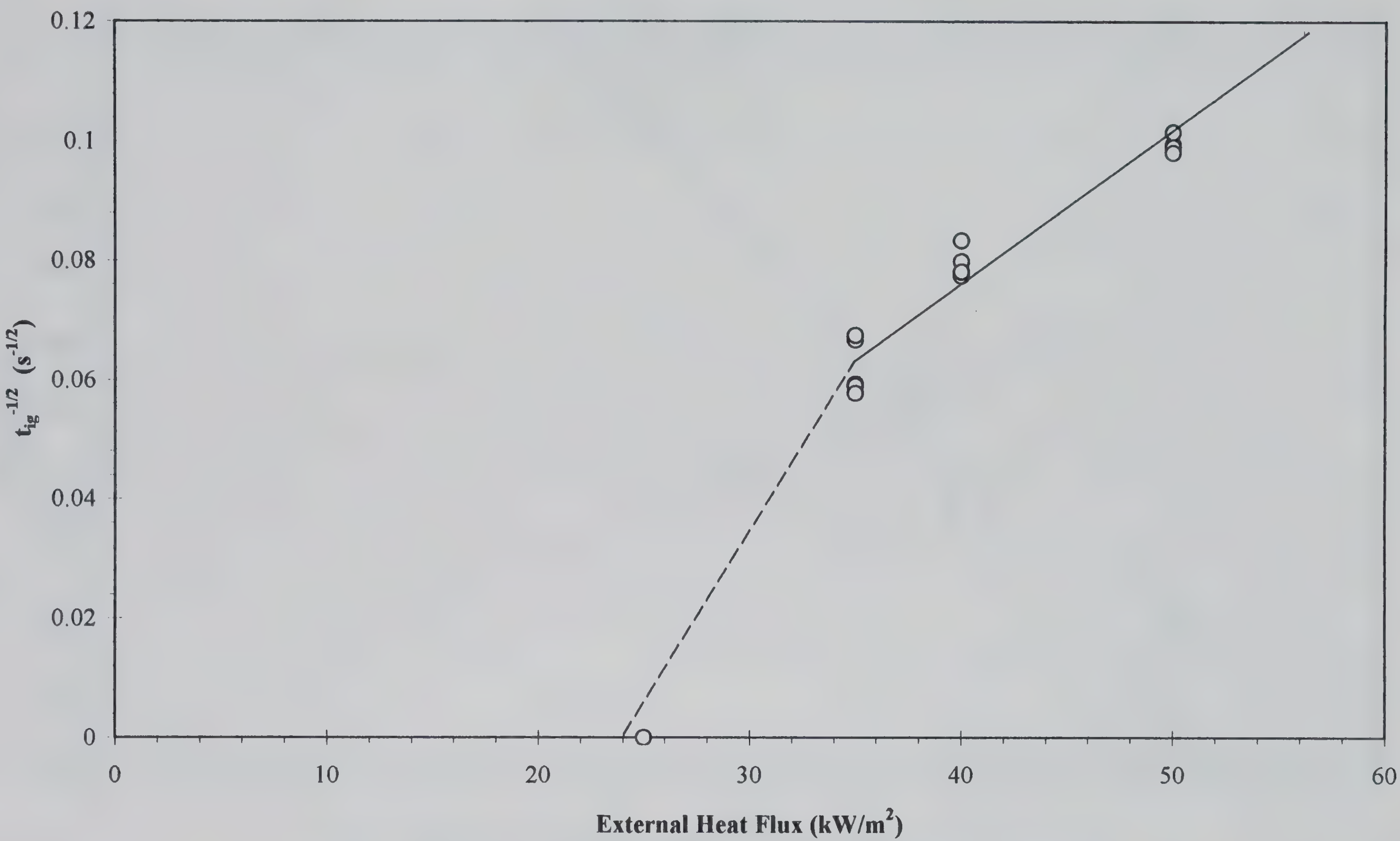
R 4.07: Fire Retarded PVC



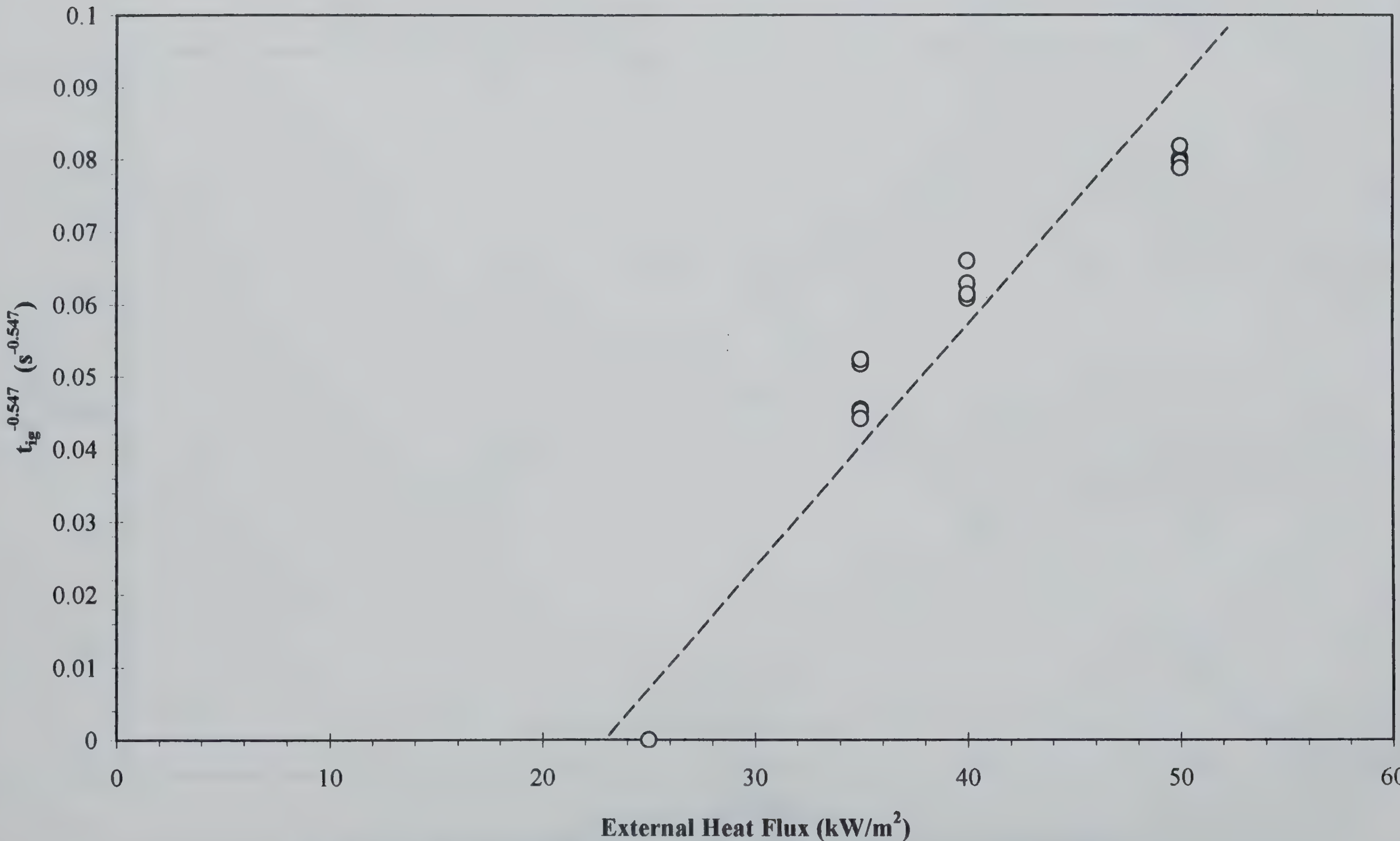
R 4.07: Fire Retarded PVC



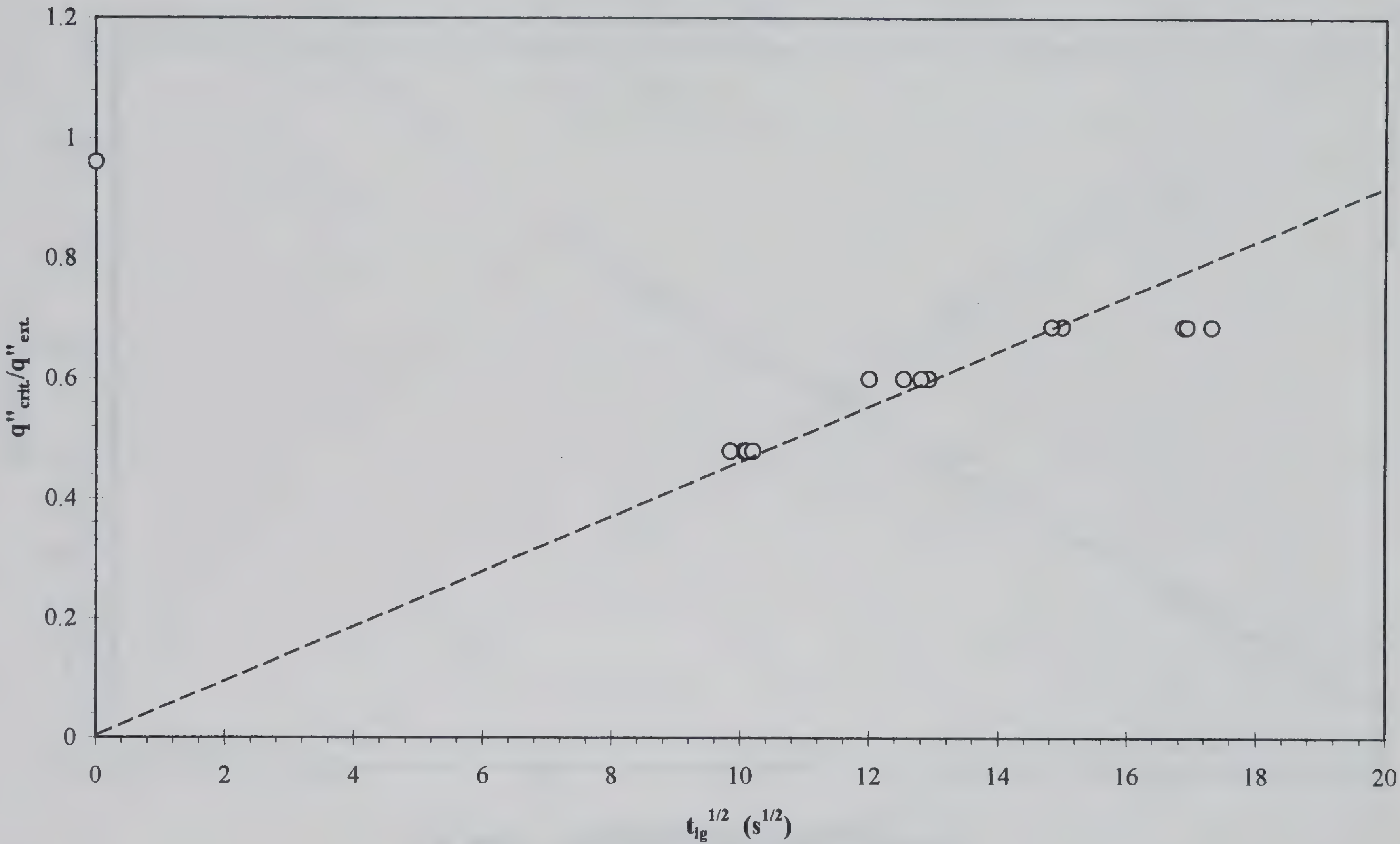
R 4.08: 3-Layered, Fire Retarded Polycarbonate Panel



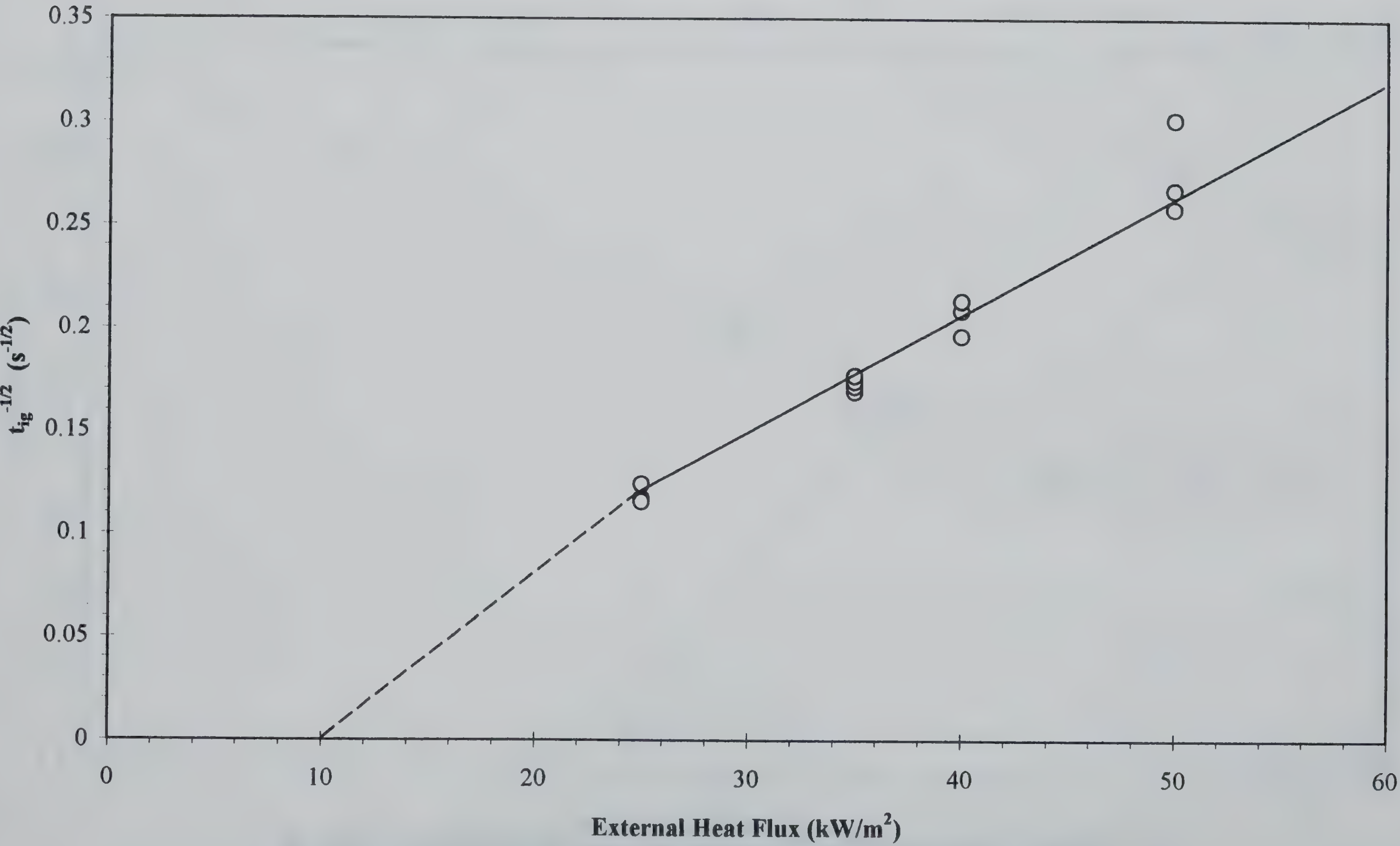
R 4.08: 3-Layered, Fire Retarded Polycarbonate Panel



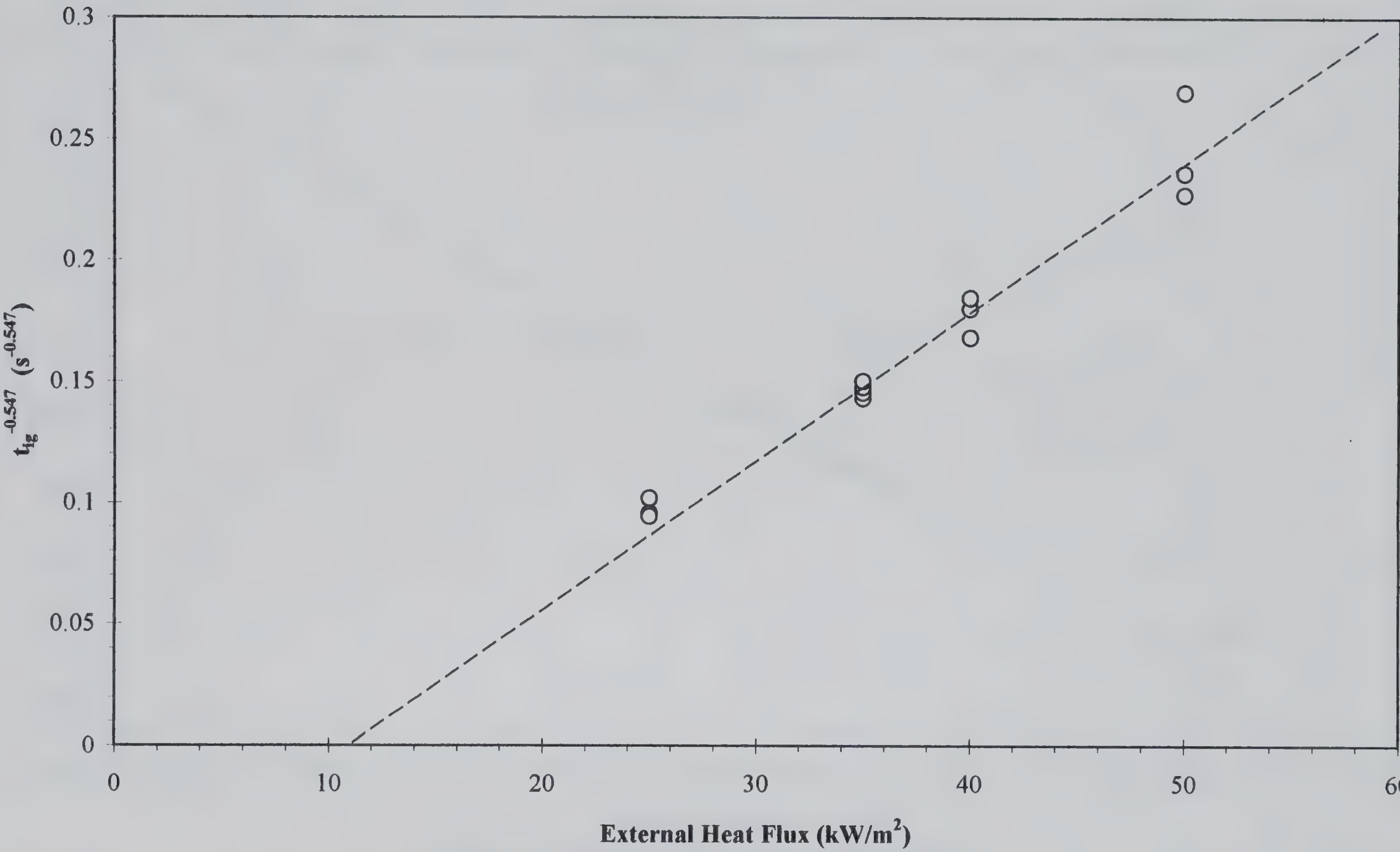
R 4.08: 3-Layered, Fire Retarded Polycarbonate Panel



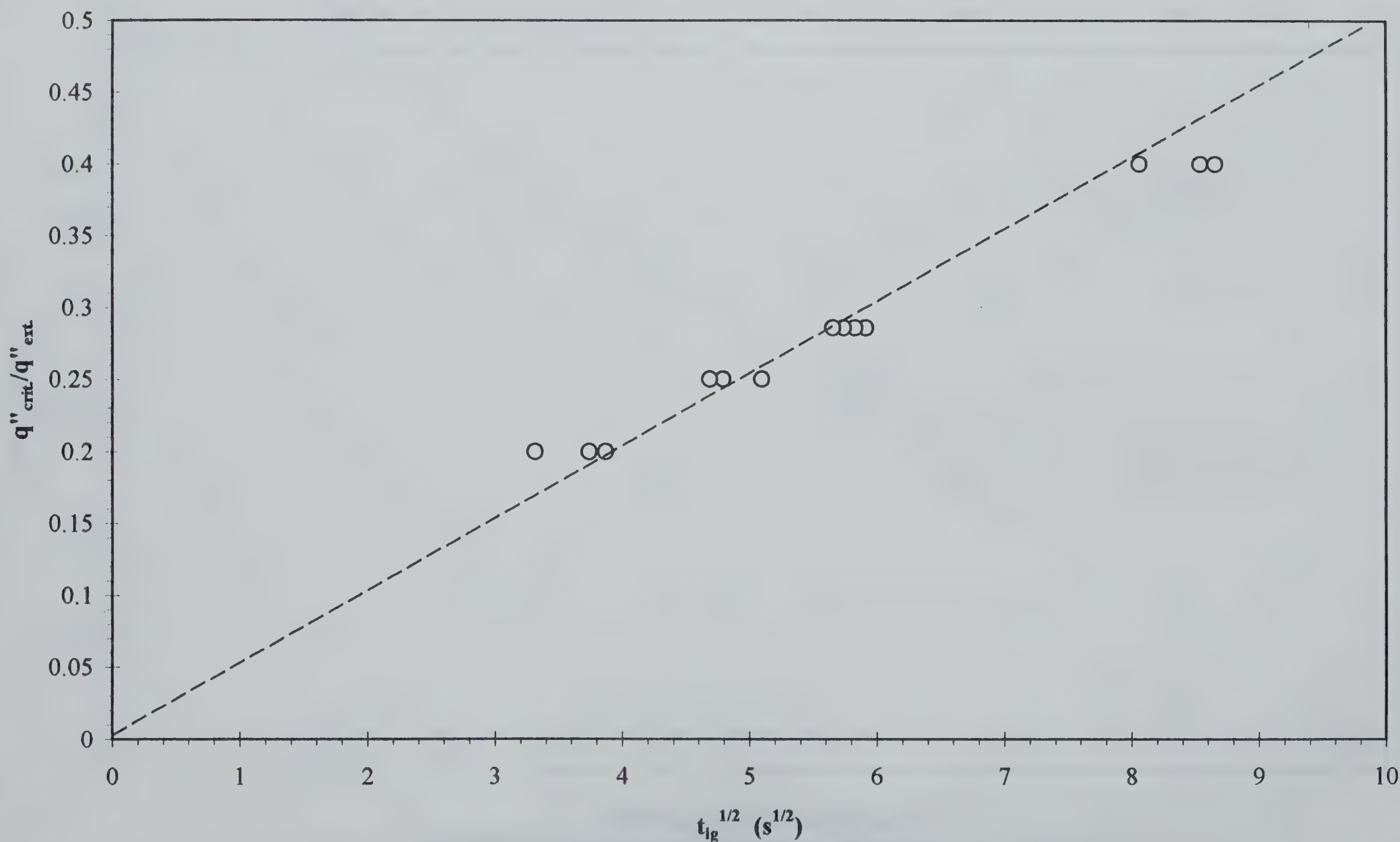
R 4.09: Varnished Massive Timber



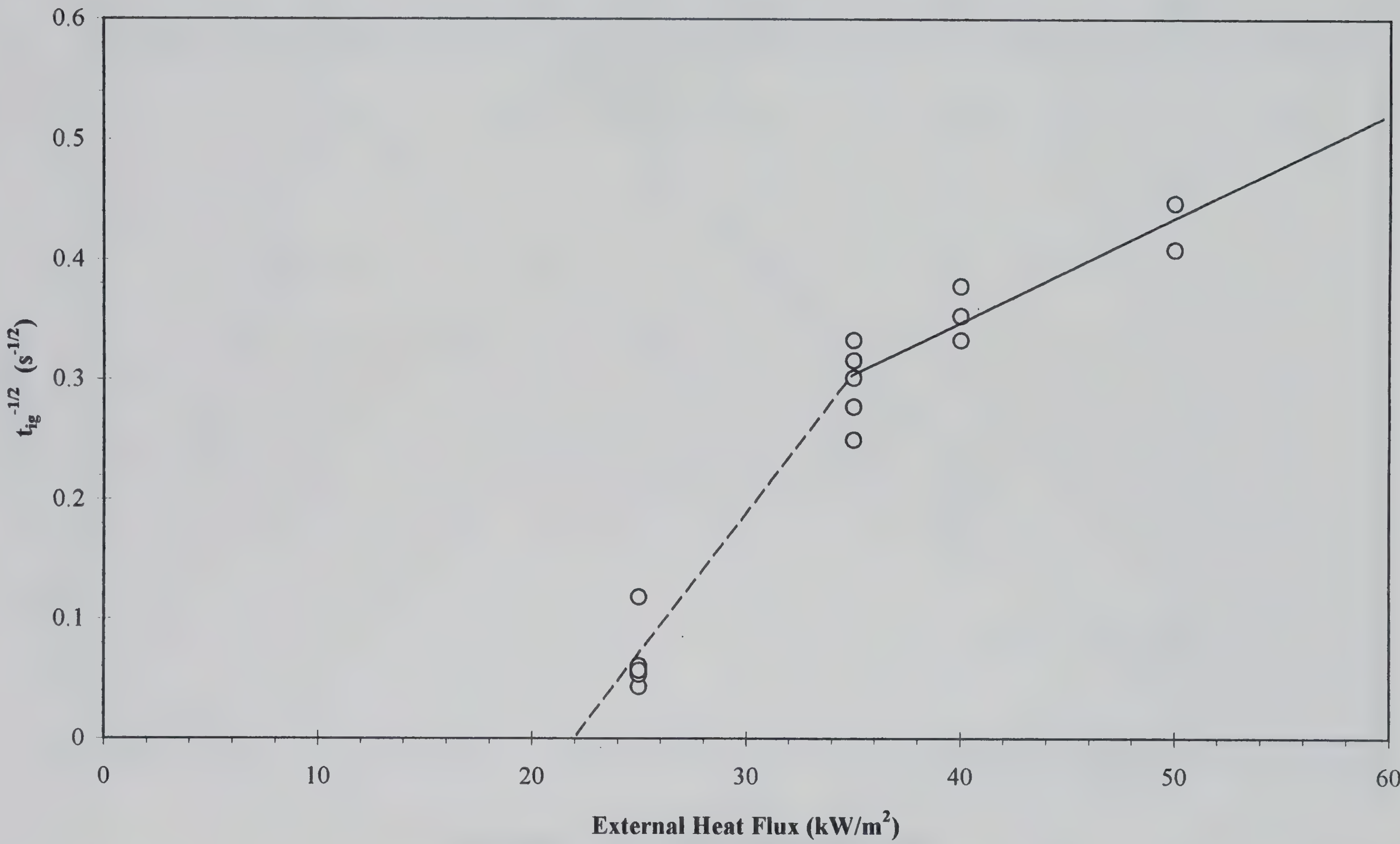
R 4.09: Varnished Massive Timber



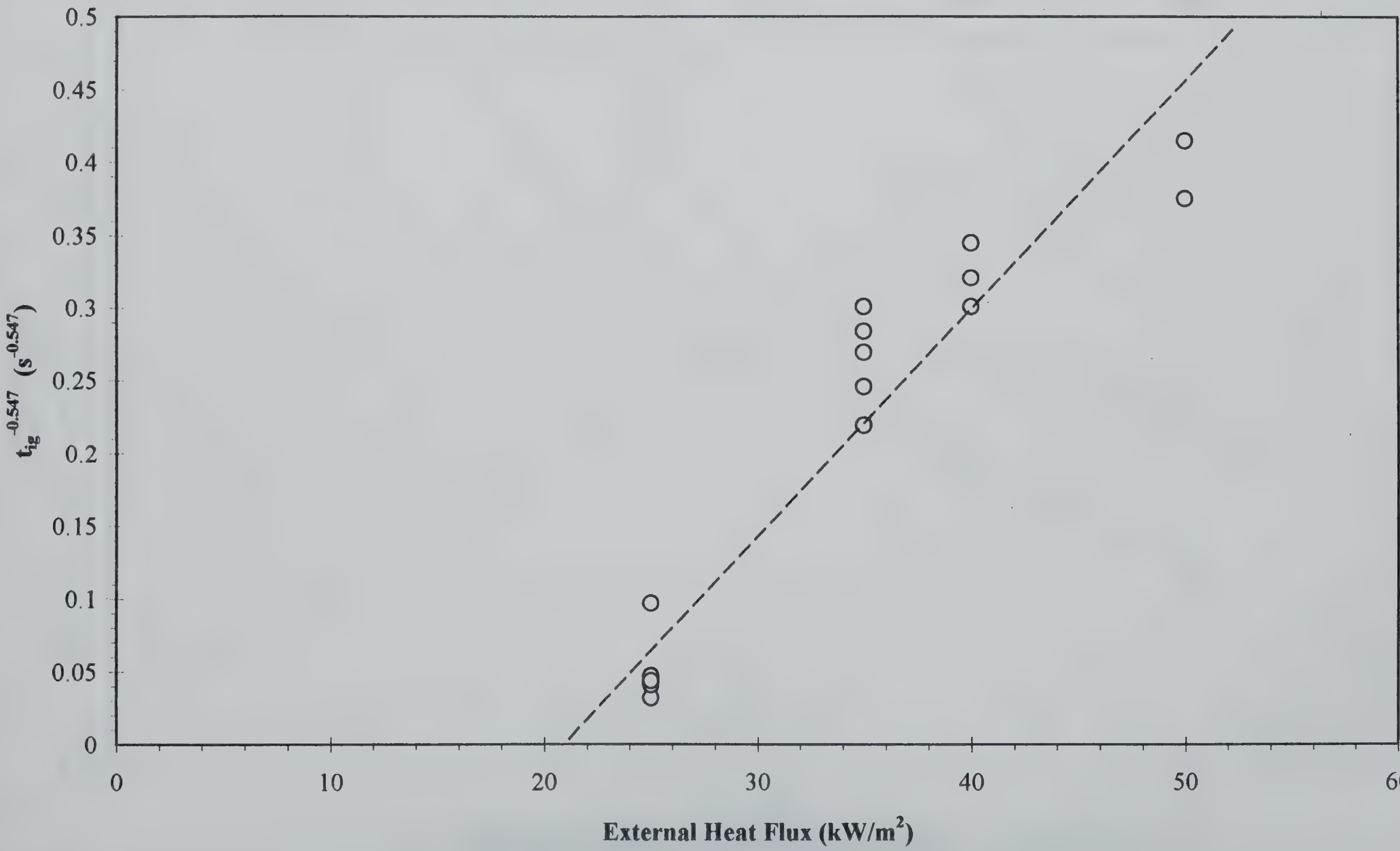
R 4.09: Varnished Massive Timber



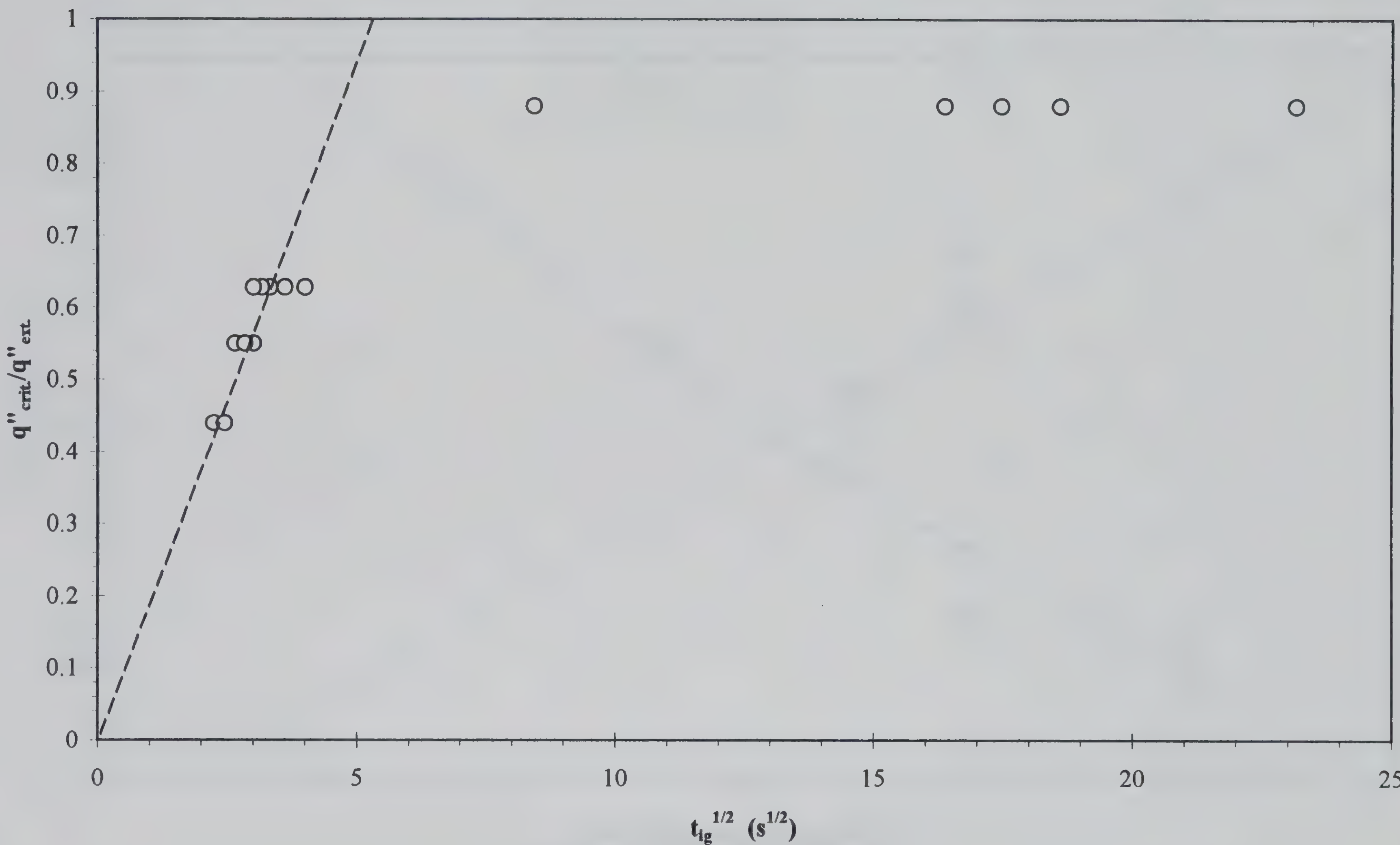
R 4.10: Fire Retarded Plywood



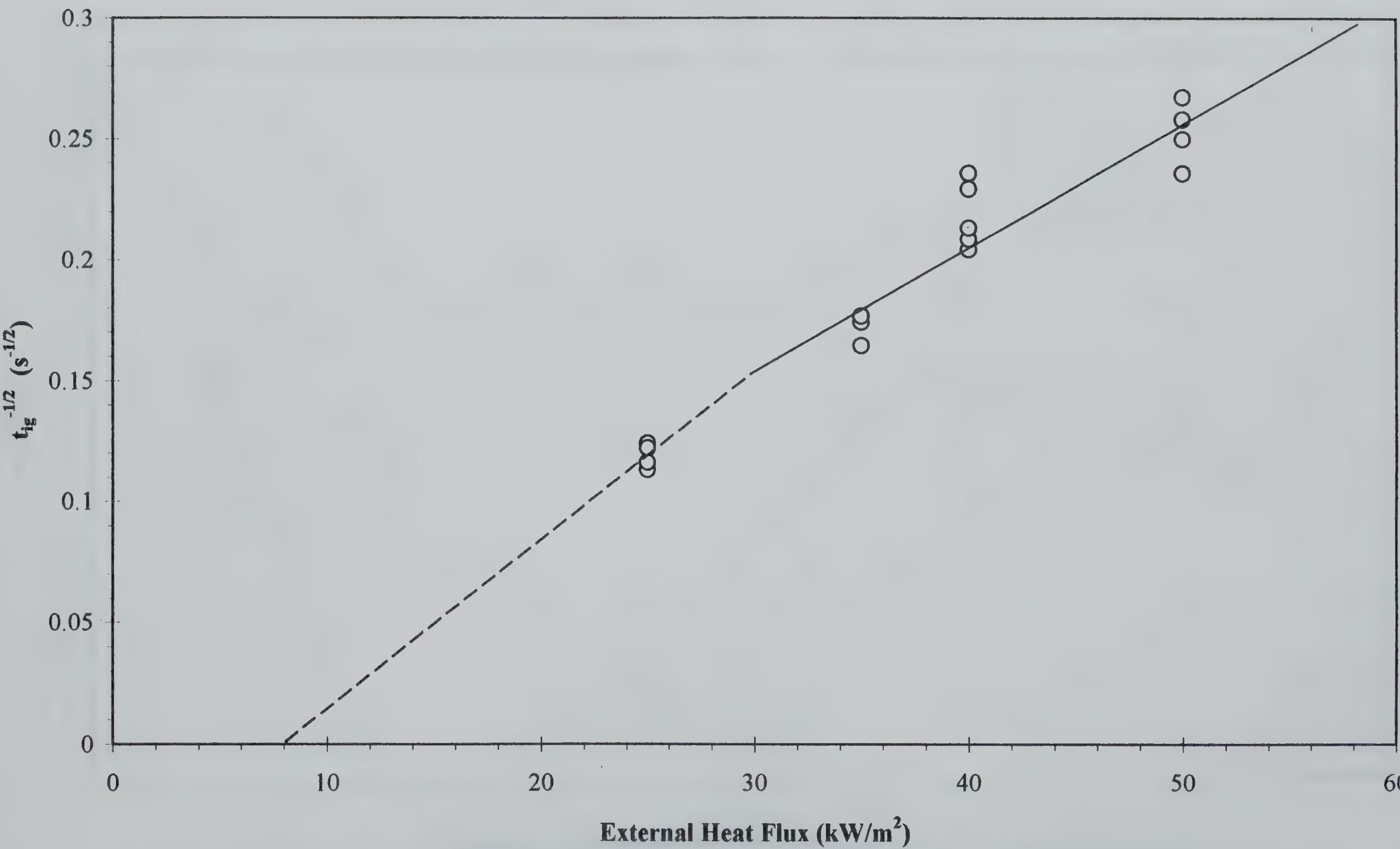
R 4.10: Fire Retarded Plywood



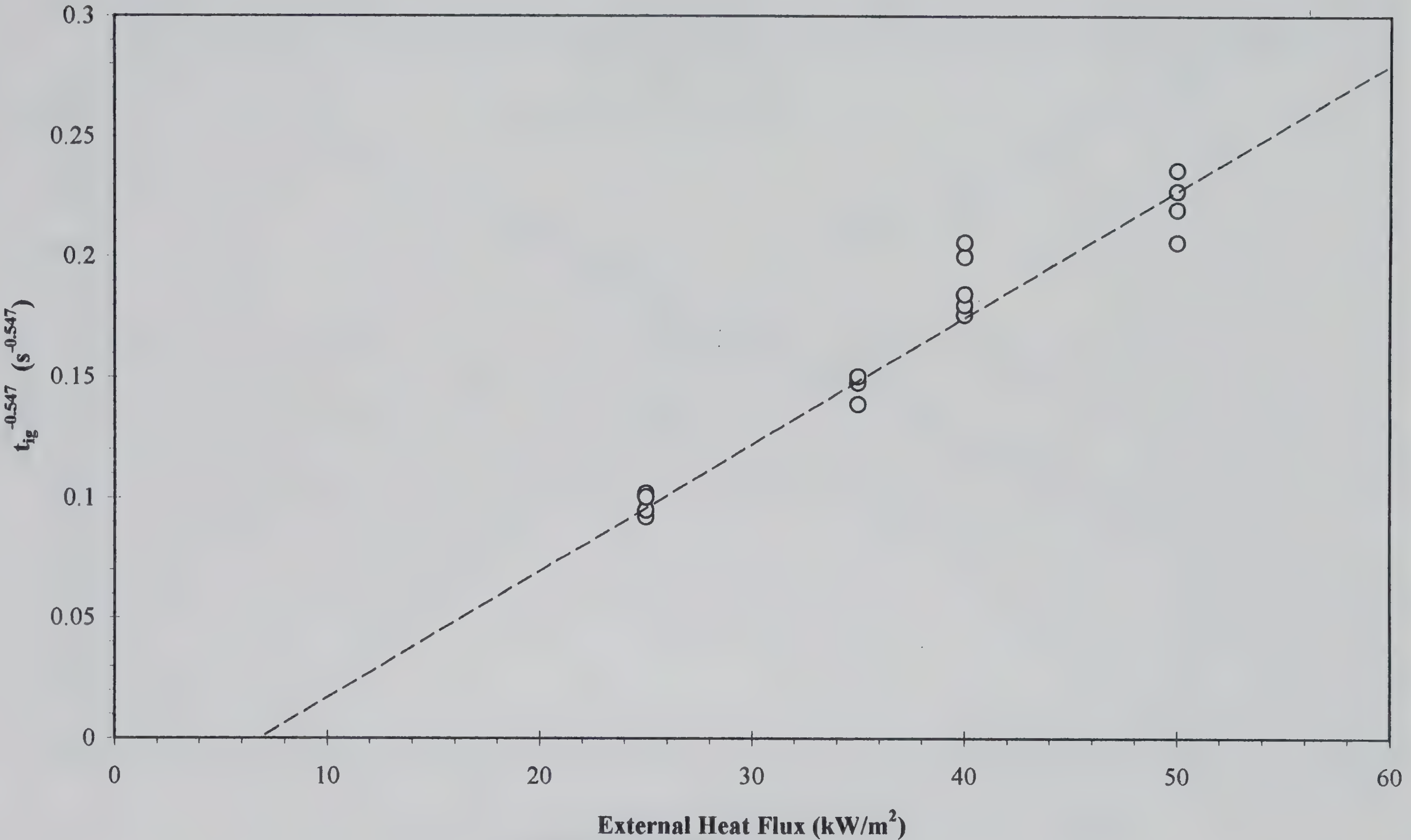
R 4.10: Fire Retarded Plywood



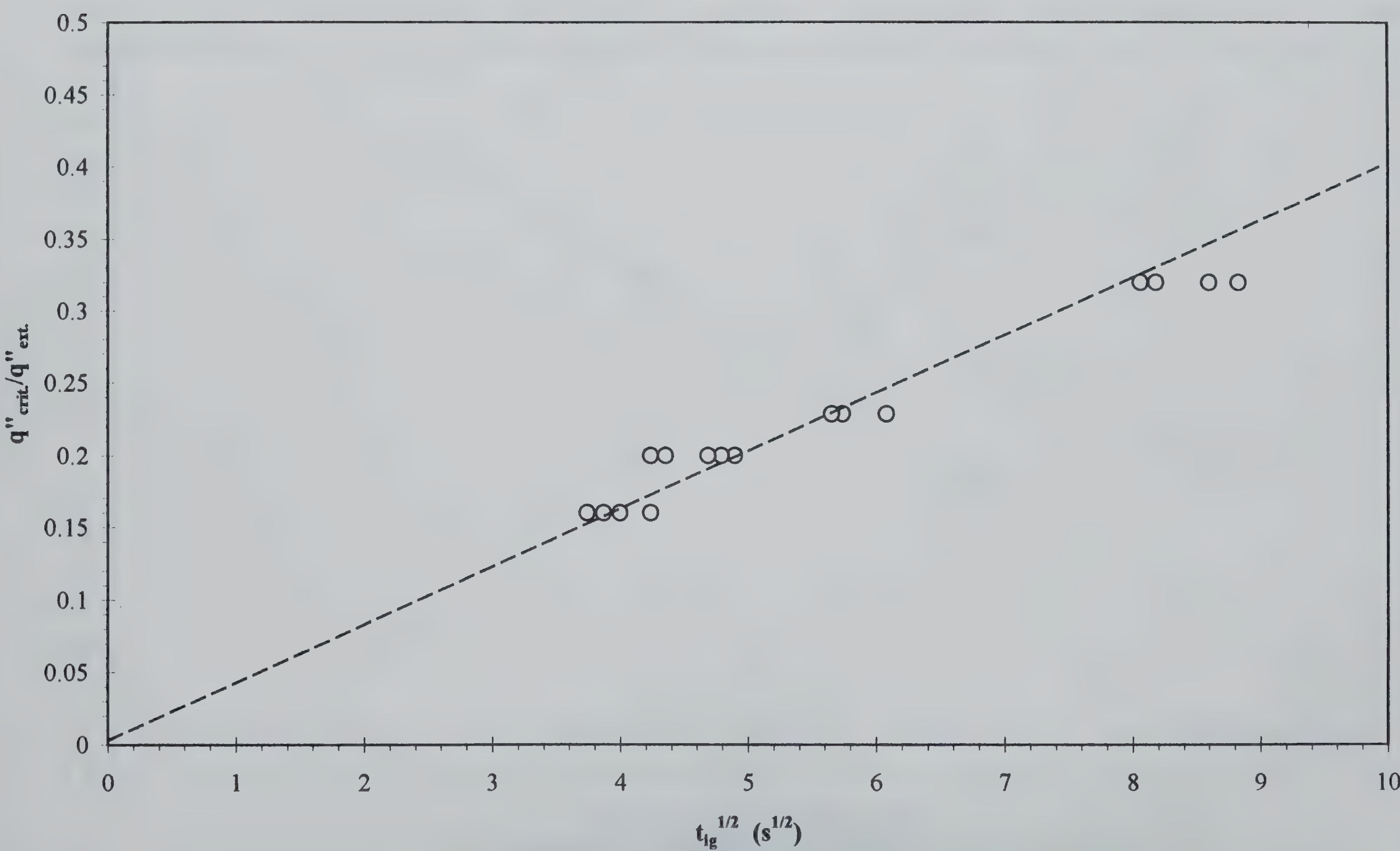
R 4.11: Normal Plywood



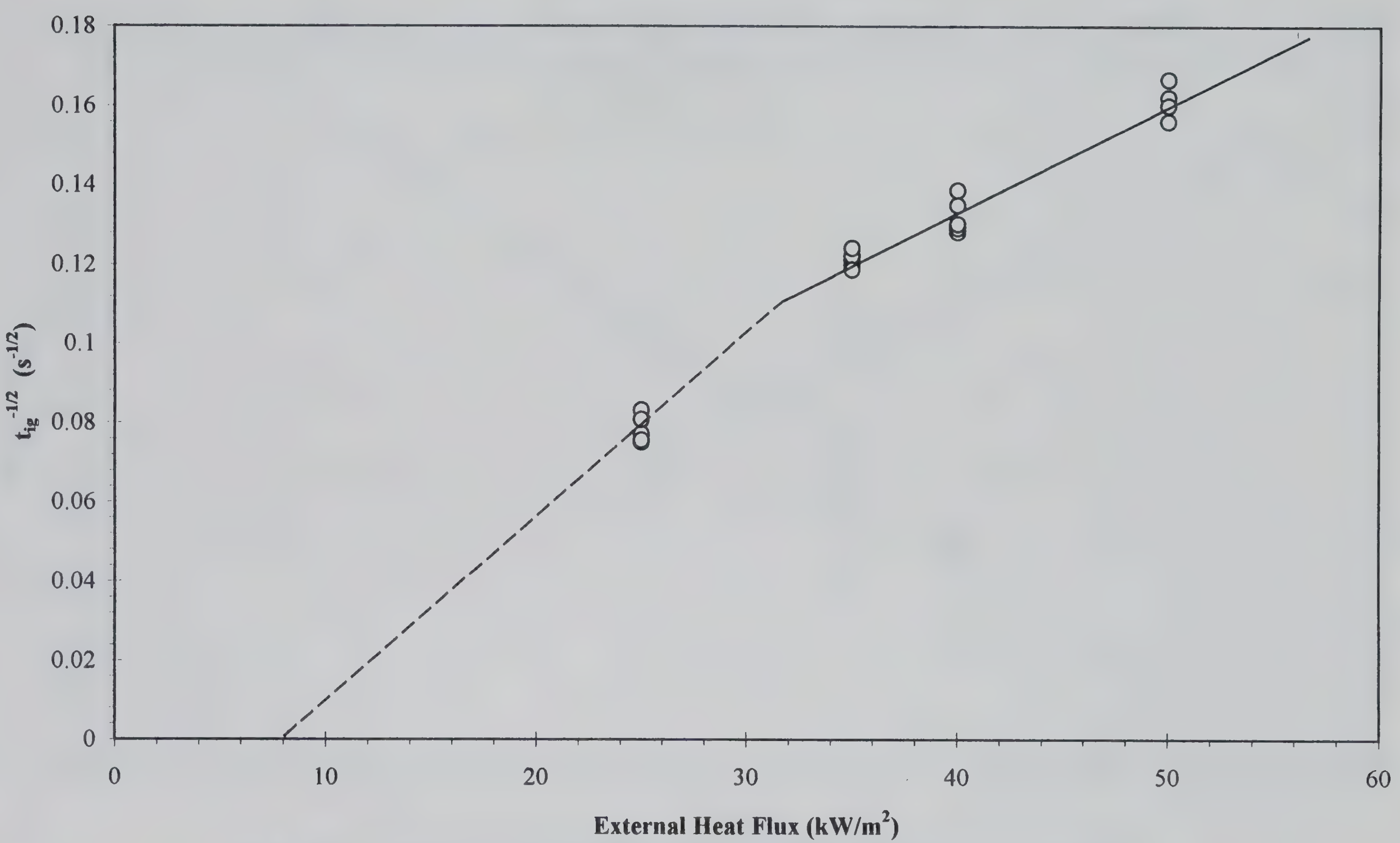
R 4.11: Normal Plywood



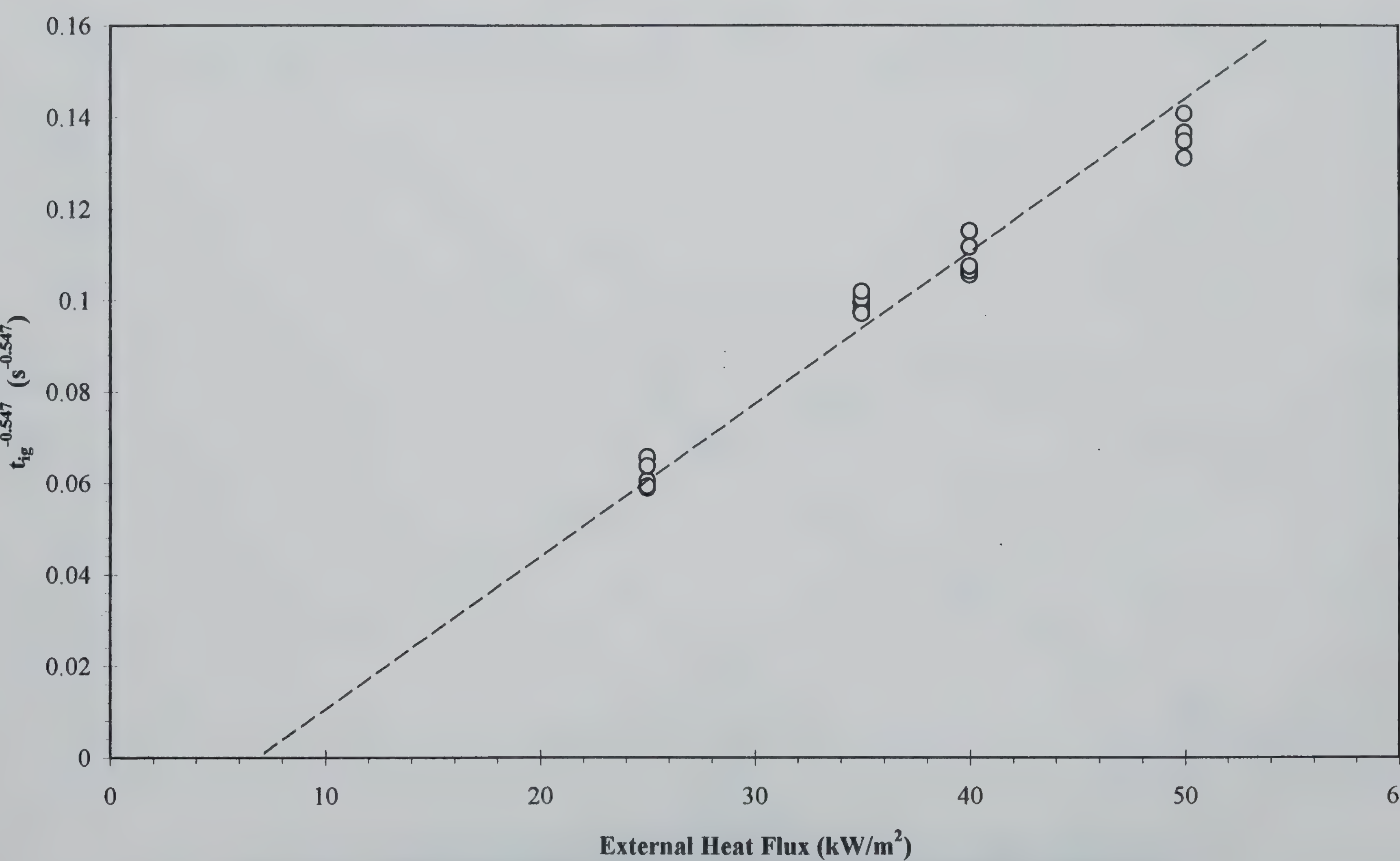
R 4.11: Normal Plywood



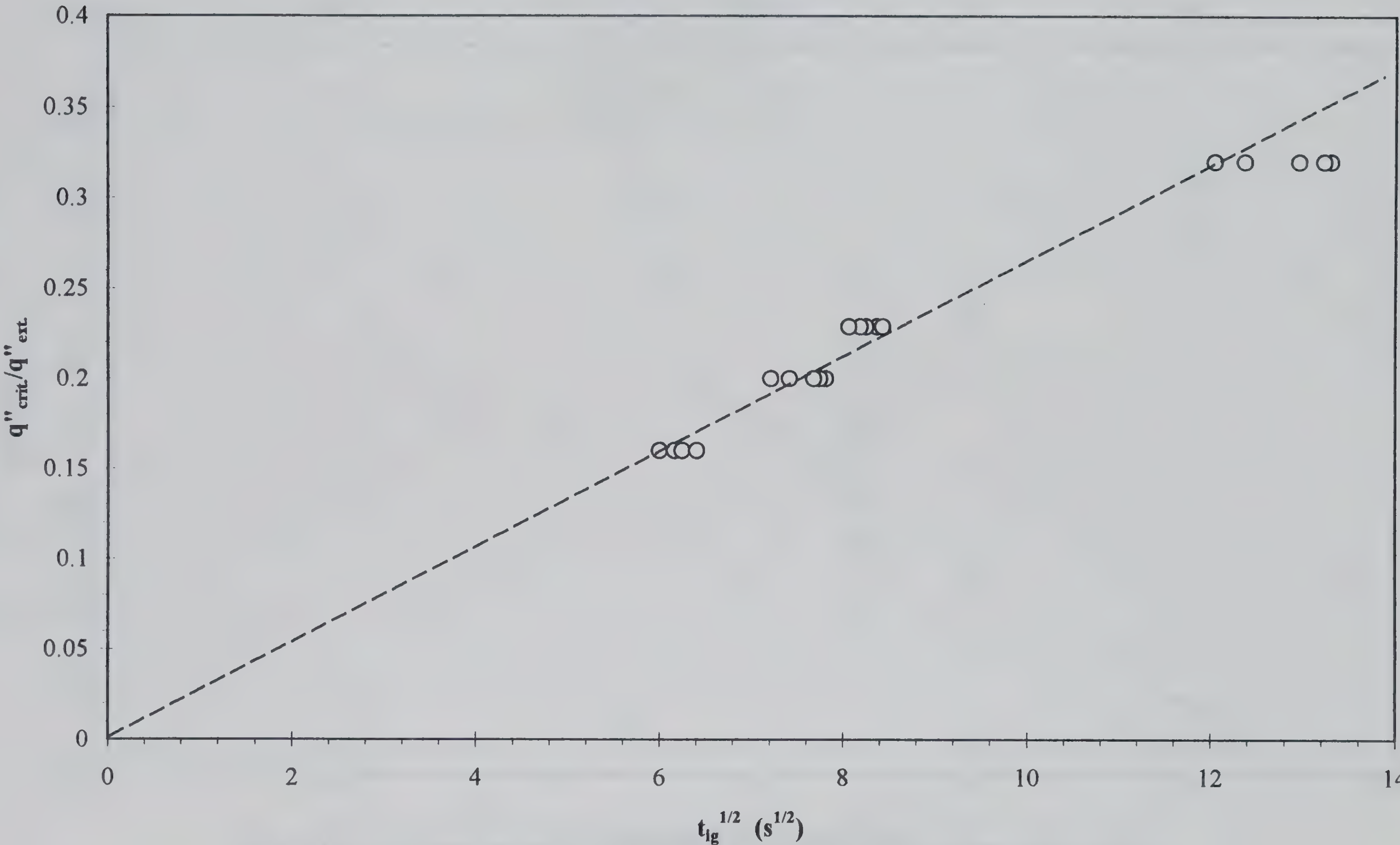
R 4.20: Fire Retarded, Expanded Polystyrene Board (40 mm)



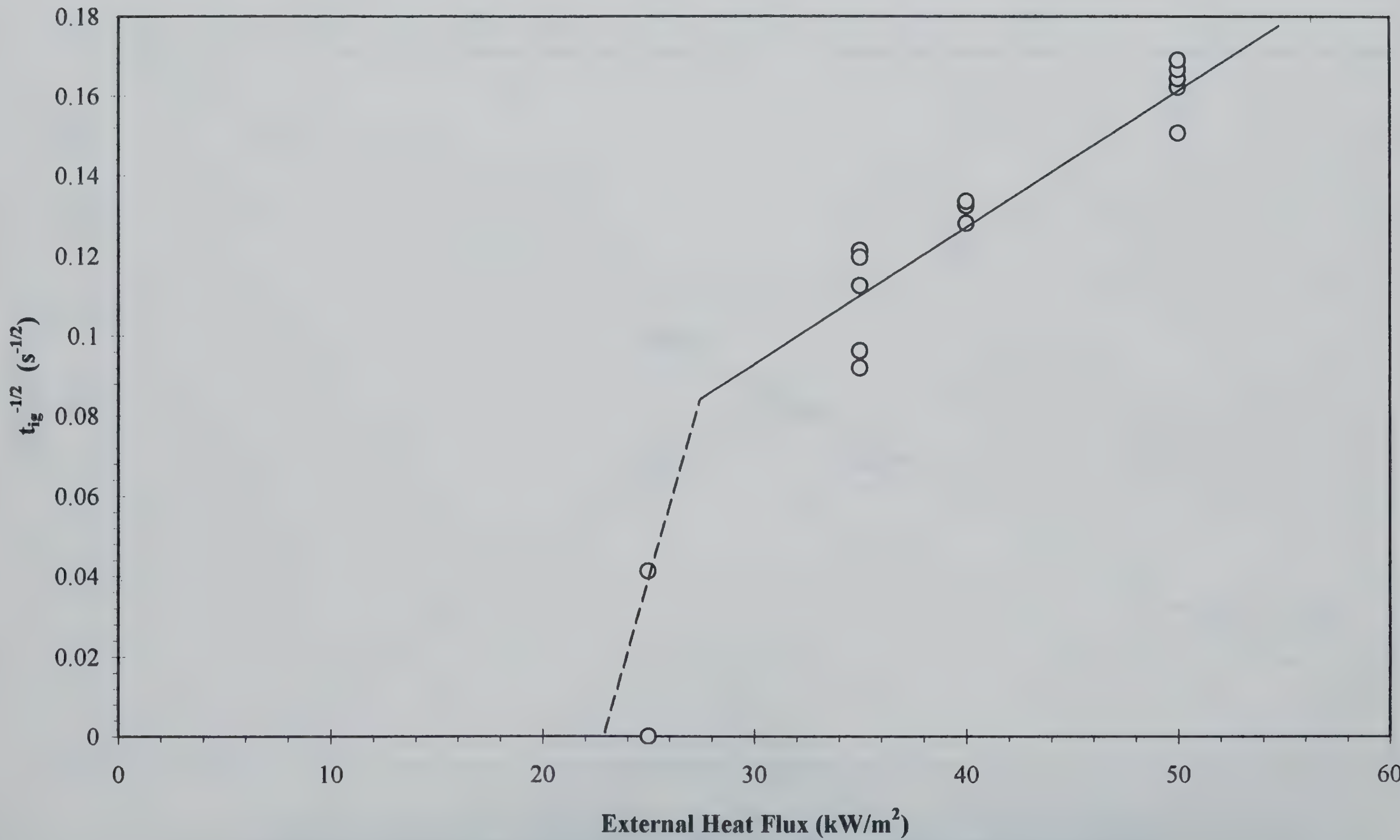
R 4.20: Fire Retarded, Expanded Polystyrene Board (40 mm)



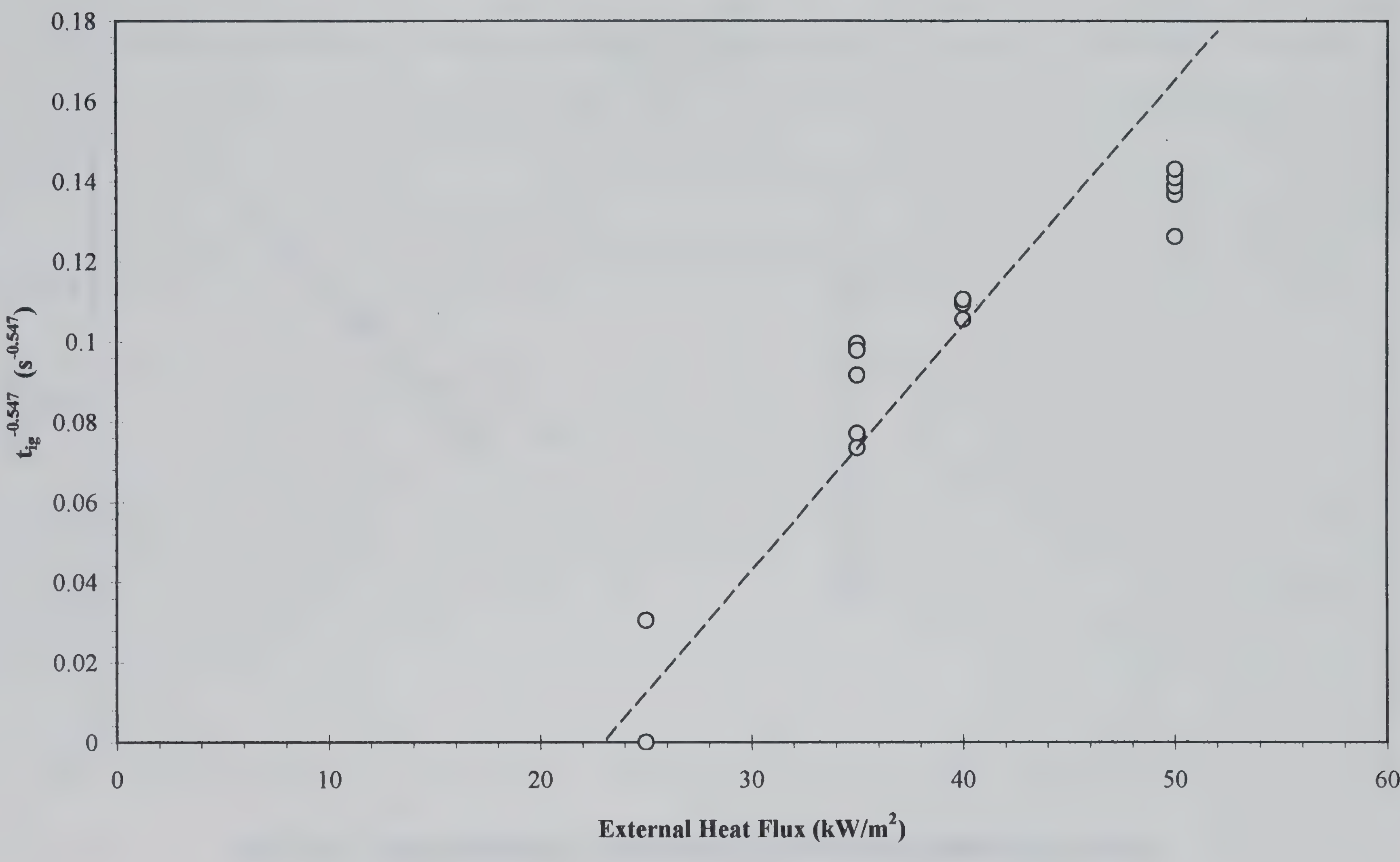
R 4.20: Fire Retarded, Expanded Polystyrene Board (40 mm)



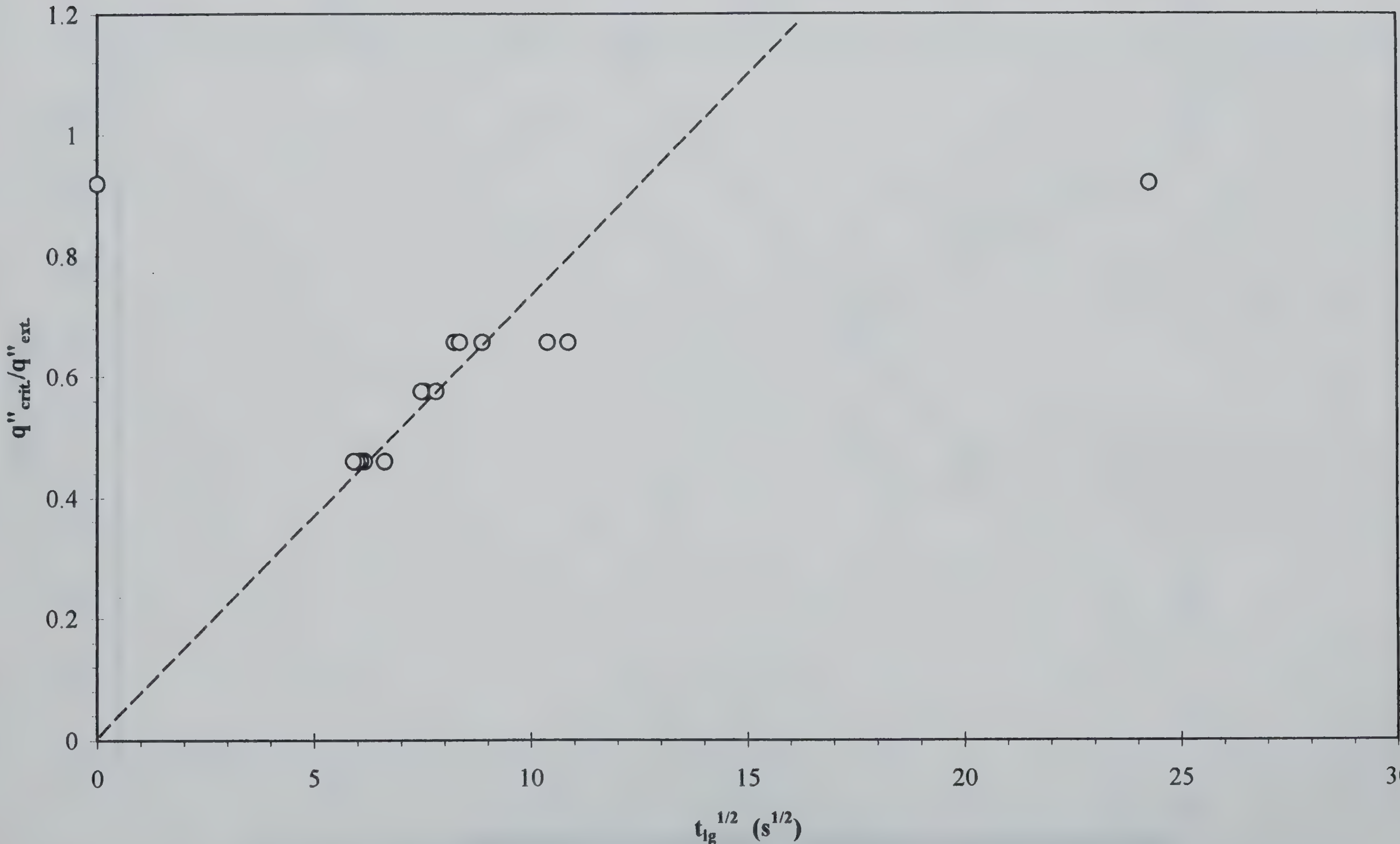
R 4.21: Fire Retarded, Expanded Polystyrene Board (80 mm)



R 4.21: Fire Retarded, Expanded Polystyrene Board (80 mm)



R 4.21: Fire Retarded, Expanded Polystyrene Board (80 mm)



A.4 – Heat of Combustion Data

Material: 4.01 F.R. Chipboard

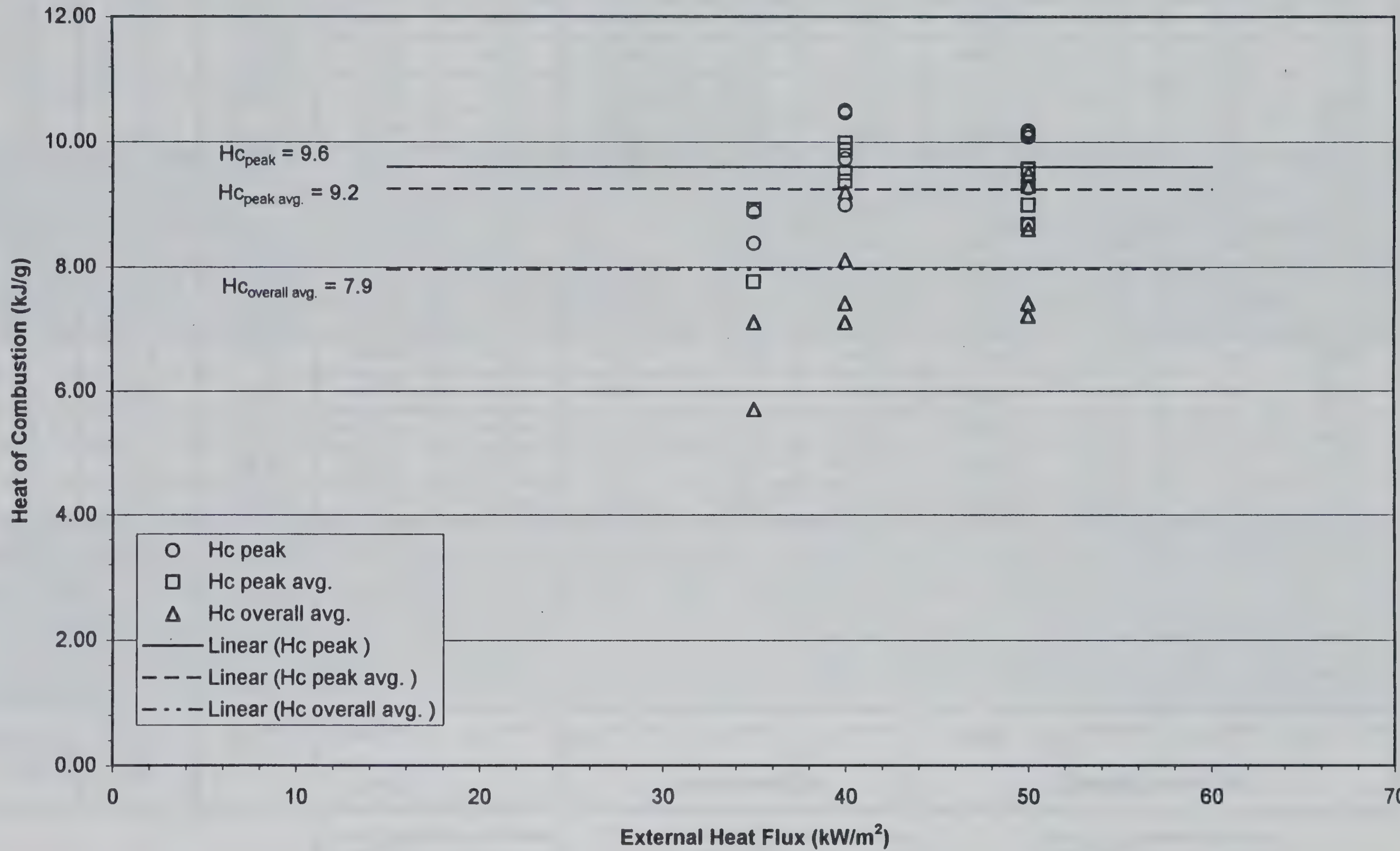
Average of Hc_{peak}	9.6

Average of $Hc_{peak\ avg.}$	9.2

Average of $Hc_{overall\ avg.}$	7.9

q''_{ext} (kW/m^2)	t_{ig} (s)	Peak			Peak Average			Overall Average			
		Q''_{peak}	Hc_{peak}	m''_{peak}	$Q''_{peak\ avg.}$	$Hc_{peak\ avg.}$	$m''_{peak\ avg.}$	-dm/dt	$m''_{overall\ avg.}$	$Hc_{overall\ avg.}$	$Q''_{overall\ avg.}$
25											
25											
25											
25											
25											
35	569	86.31	8.87	9.73	79.56	8.91	8.93	0.0719	8.170	7.1	58.01
35											
35	594	75.79	8.37	9.05	70.02	7.75	9.03	0.0670	7.614	5.7	43.40
35											
35											
40											
40	530	114.85	10.51	10.93	104.93	9.86	10.64	0.0784	8.909	7.1	63.25
40	541	108.28	10.47	10.34	97.59	9.99	9.77	0.0770	8.750	8.1	70.88
40	280	104.98	9.73	10.79	95.40	9.37	10.18	0.0729	8.284	7.4	61.30
40	598	97.27	8.99	10.82	89.84	9.50	9.46	0.0797	9.057	9.2	83.32
50	504	98.97	8.67	11.42	91.23	8.99	10.15	0.0833	9.466	8.6	81.41
50	410	97.73	9.27	10.54	87.17	8.68	10.04	0.0809	9.193	7.4	68.03
50	564	118.40	10.18	11.63	109.40	9.57	11.43	0.0951	10.807	9.3	100.50
50	245	109.79	10.08	10.89	99.31	9.56	10.39	0.0761	8.648	7.2	62.26
50	505	103.95	10.13	10.26	96.29	9.29	10.36	0.0887	10.080	9.5	95.76

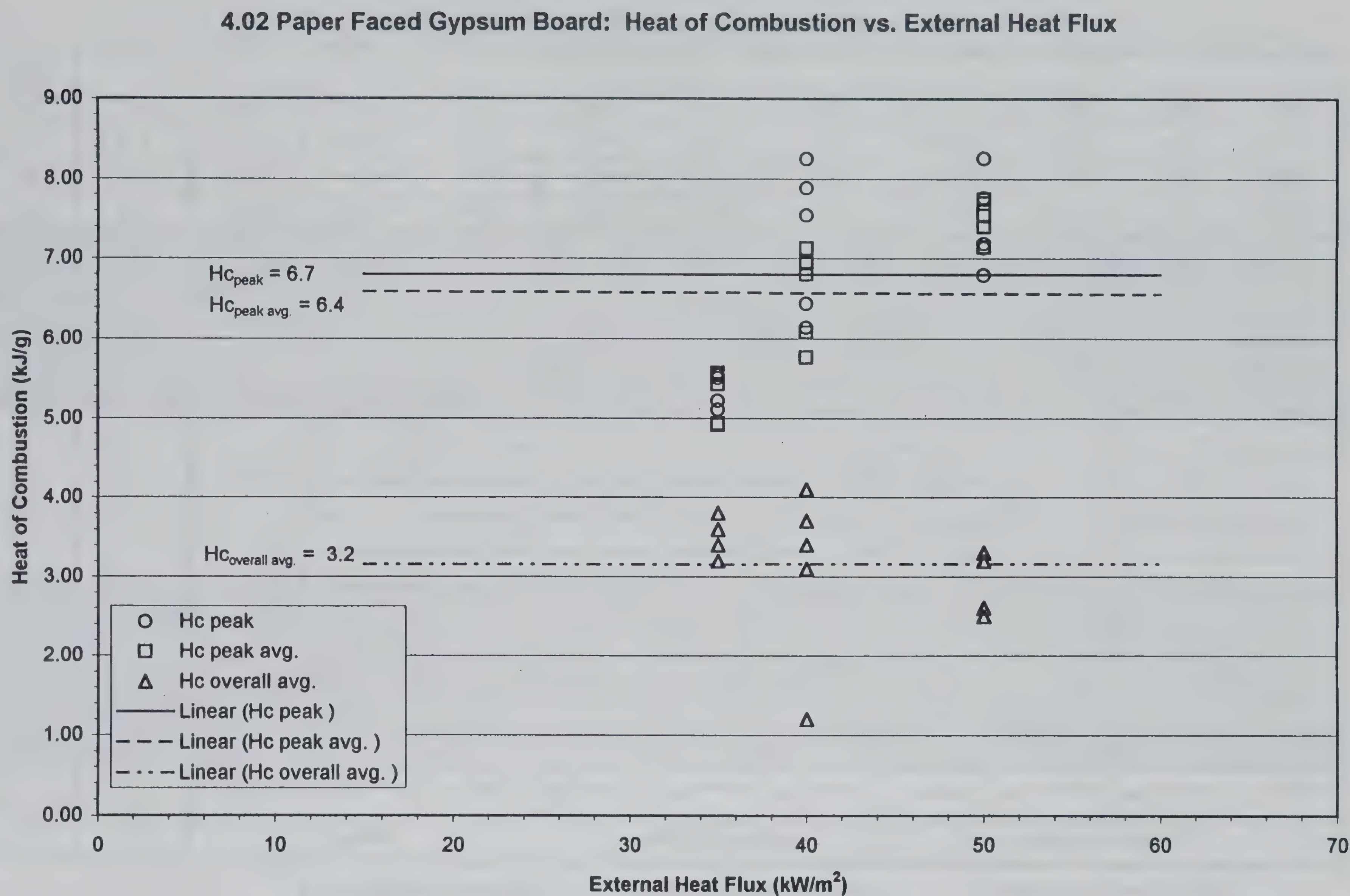
4.01 F.R. Chipboard: Heat of Combustion vs. External Heat Flux



Material: 4.02 Paper Faced Gypsum Board

Average of Hc_{peak}	6.7	Average of $Hc_{peak\ avg.}$	6.4	Average of $Hc_{overall\ avg.}$	3.2

q''_{ext} (kW/m^2)	t_{ig} (s)	Peak			Peak Average			Overall Average			
		Q''_{peak}	Hc_{peak}	m''_{peak}	$Q''_{peak\ avg.}$	$Hc_{peak\ avg.}$	$m''_{peak\ avg.}$	-dm/dt	$m''_{overall\ avg.}$	$Hc_{overall\ avg.}$	$Q''_{overall\ avg.}$
25											
25											
25											
25											
25											
35	106	74.00	5.11	14.48	73.67	4.91	15.00	0.0676	7.682	3.2	24.58
35	107	76.81	5.22	14.71	74.19	4.93	15.05	0.0674	7.659	3.4	26.04
35	110	81.09	5.50	14.74	77.16	5.43	14.21	0.0689	7.830	3.6	28.19
35	109	80.30	5.54	14.49	80.30	5.54	14.49	0.0670	7.614	3.8	28.93
35	110	81.09	5.56	14.58	81.09	5.56	14.58	0.0690	7.841	3.4	26.66
40	58	94.98	6.14	15.47	90.44	5.76	15.70	0.0802	9.114	1.2	10.94
40	61	92.68	6.44	14.39	90.36	6.08	14.86	0.0730	8.295	3.7	30.69
40	58	95.78	8.25	11.61	91.12	7.12	12.80	0.0783	8.898	3.4	30.25
40	57	98.24	7.88	12.47	90.88	6.80	13.36	0.0797	9.057	4.1	37.13
40	64	96.22	7.54	12.76	86.98	6.94	12.53	0.0780	8.864	3.1	27.48
50	48	101.22	6.79	14.91	99.79	7.40	13.49	0.0816	9.273	2.5	23.18
50	43	102.55	8.26	12.42	97.95	7.14	13.72	0.0791	8.989	3.3	29.66
50	43	101.33	7.13	14.21	101.30	7.69	13.17	0.0837	9.511	3.2	30.44
50	45	106.17	7.76	13.68	95.80	7.53	12.72	0.0770	8.750	2.6	22.75
50	42	100.70	7.18	14.03	99.05	7.74	12.80	0.0759	8.625	3.3	28.46


4.02 Paper Faced Gypsum Board: Heat of Combustion vs. External Heat Flux
Heat of Combustion (kJ/g)
External Heat Flux (kW/m2)
Hcpeak = 6.7
Hcpeak avg. = 6.4
Hcoverall avg. = 3.2
Hc peak
Hc peak avg.
Hc overall avg.
Linear (Hc peak)
Linear (Hc peak avg.)
Linear (Hc overall avg.)
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
0
10
20
30
40
50
60
70

Material: 4.03 Polyurethane Foam Panel with Aluminum Faced Paper

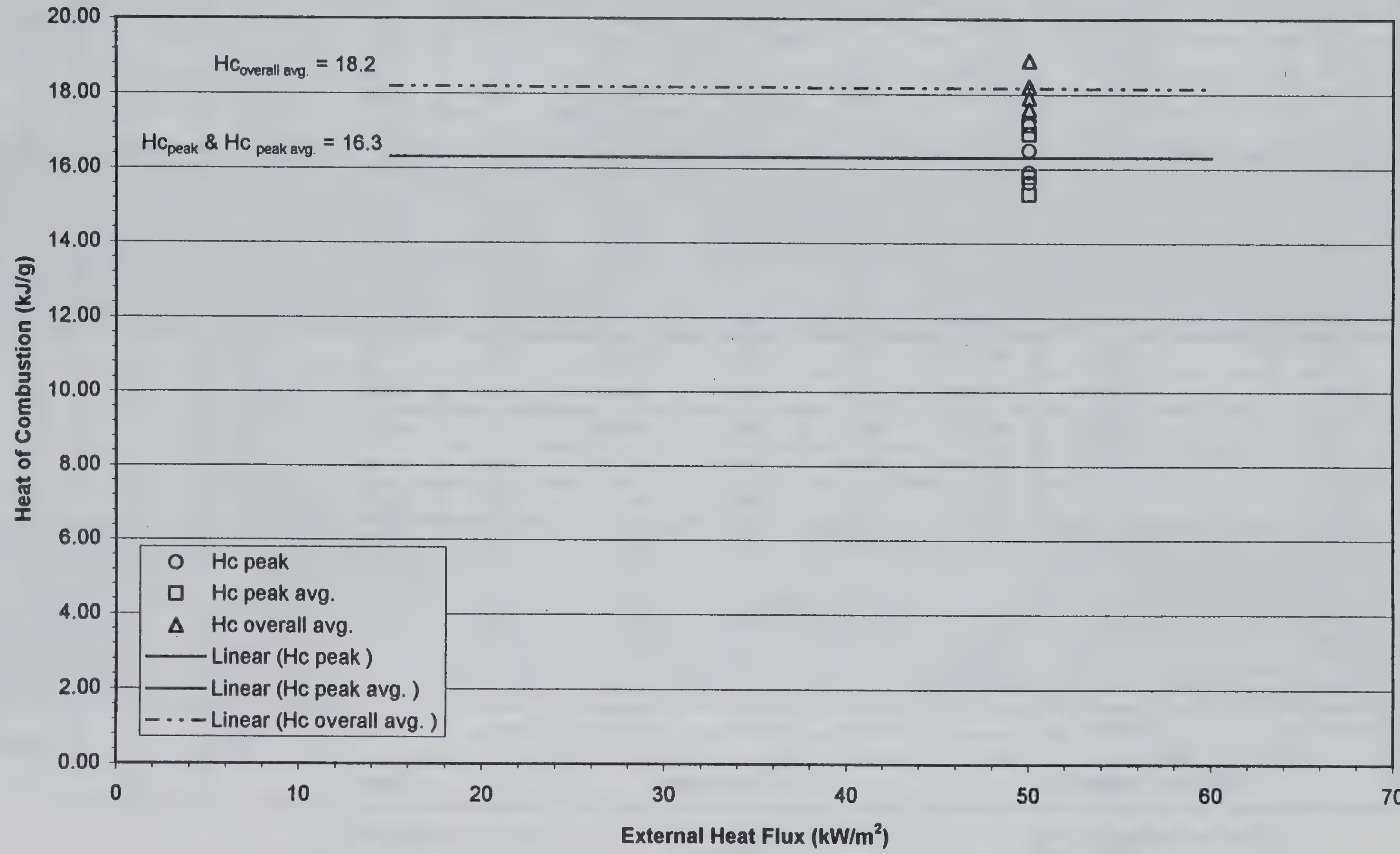
Average of Hc_{peak}	16.3

Average of $Hc_{peak\ avg.}$	16.3

Average of $Hc_{overall\ avg.}$	18.2

q''_{ext} (kW/m^2)	t_{ig} (s)	Peak			Peak Average			Overall Average			
		Q''_{peak}	Hc_{peak}	m''_{peak}	$Q''_{peak\ avg.}$	$Hc_{peak\ avg.}$	$m''_{peak\ avg.}$	-dm/dt	$m''_{overall\ avg.}$	$Hc_{overall\ avg.}$	$Q''_{overall\ avg.}$
25											
25											
25											
25											
25											
35											
35											
35											
35											
35											
40											
40											
40											
40											
40											
50	467	229.53	15.63	14.69	210.97	15.78	13.37	0.0825	9.375	17.6	165.00
50	391	180.68	15.91	11.36	165.61	15.31	10.82	0.0654	7.432	18.2	135.26
50	215	174.17	16.50	10.56	155.47	17.16	9.06	0.0638	7.250	18.9	137.03
50	478	299.09	17.18	17.41	279.71	16.93	16.52	0.0902	10.250	17.9	183.48
50											

R 4.03 Heat of Combustion vs. External Heat Flux



Material: 4.04 Polyurethane with Paper Backing

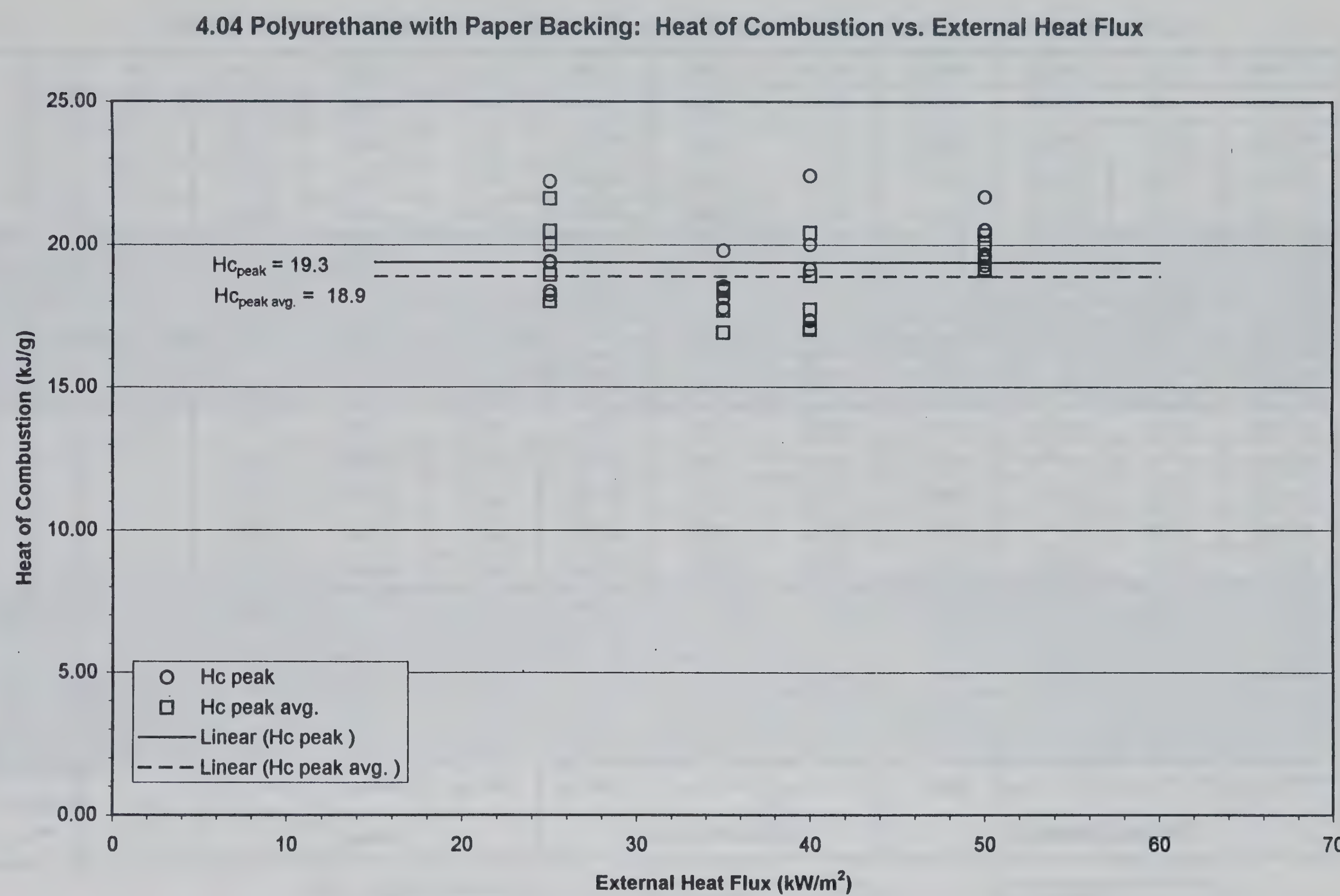
Average of Hc_{peak}	19.3

Average of $Hc_{peak\ avg.}$	18.9

Average of $Hc_{overall\ avg.}$	----

q''_{ext} (kW/m^2)	t_{ig} * (s)	Peak			Peak Average			Overall Average			
		Q''_{peak}	Hc_{peak}	m''_{peak}	$Q''_{peak\ avg.}$	$Hc_{peak\ avg.}$	$m''_{peak\ avg.}$	-dm/dt	$m''_{overall\ avg.}$	$Hc_{overall\ avg.}$ *	$Q''_{overall\ avg.}$
25		276.54	19.43	14.23	267.06	21.61	12.36	0.0493	5.602		0.00
25		220.80	18.23	12.11	198.56	18.01	11.02	0.0571	6.489		0.00
25		214.99	18.37	11.70	196.75	18.95	10.38	0.0649	7.375		0.00
25		212.82	22.21	9.58	206.71	20.00	10.34	0.0536	6.091		0.00
25		277.83	19.37	14.34	276.07	20.47	13.49	0.0528	6.000		0.00
35		239.86	19.80	12.11	232.49	18.42	12.62	0.0665	7.557		0.00
35		278.73	18.14	15.37	261.16	18.47	14.14	0.0539	6.125		0.00
35		265.33	17.79	14.91	240.92	17.69	13.62	0.0698	7.932		0.00
35		278.35	18.56	15.00	245.85	18.36	13.39	0.0577	6.557		0.00
35		273.30	17.77	15.38	256.72	16.92	15.17	0.0678	7.705		0.00
40		242.77	17.36	13.98	227.62	17.02	13.37	0.0622	7.068		0.00
40		315.60	22.41	14.08	304.23	20.42	14.90	0.0575	6.534		0.00
40		302.75	20.00	15.14	292.13	18.92	15.44	0.0554	6.295		0.00
40		292.31	19.15	15.26	269.56	17.72	15.21	0.0730	8.295		0.00
40		246.77	17.33	14.24	230.29	17.08	13.48	0.0731	8.307		0.00
50		340.86	20.52	16.61	304.44	20.05	15.18	0.0779	8.852		0.00
50		311.15	19.68	15.81	292.23	19.16	15.25	0.0878	9.977		0.00
50		375.36	19.28	19.47	347.03	19.42	17.87	0.0669	7.602		0.00
50		304.12	19.55	15.56	278.80	19.10	14.60	0.0865	9.830		0.00
50		357.31	21.67	16.49	351.24	20.34	17.27	0.0724	8.227		0.00

* The LSF data for this material was incomplete. Therefore the ignition time and overall heat of combustion values have been ommitted


4.04 Polyurethane with Paper Backing: Heat of Combustion vs. External Heat Flux
Heat of Combustion (kJ/g)
25.00
20.00
15.00
10.00
5.00
0.00
0
10
20
30
40
50
60
70
External Heat Flux (kW/m2)
Hcpeak = 19.3
Hcpeak avg. = 18.9
Hc peak
Hc peak avg.
Linear (Hc peak)
Linear (Hc peak avg.)

Material: 4.05 F.R. Extruded Polystyrene Board (40 mm)

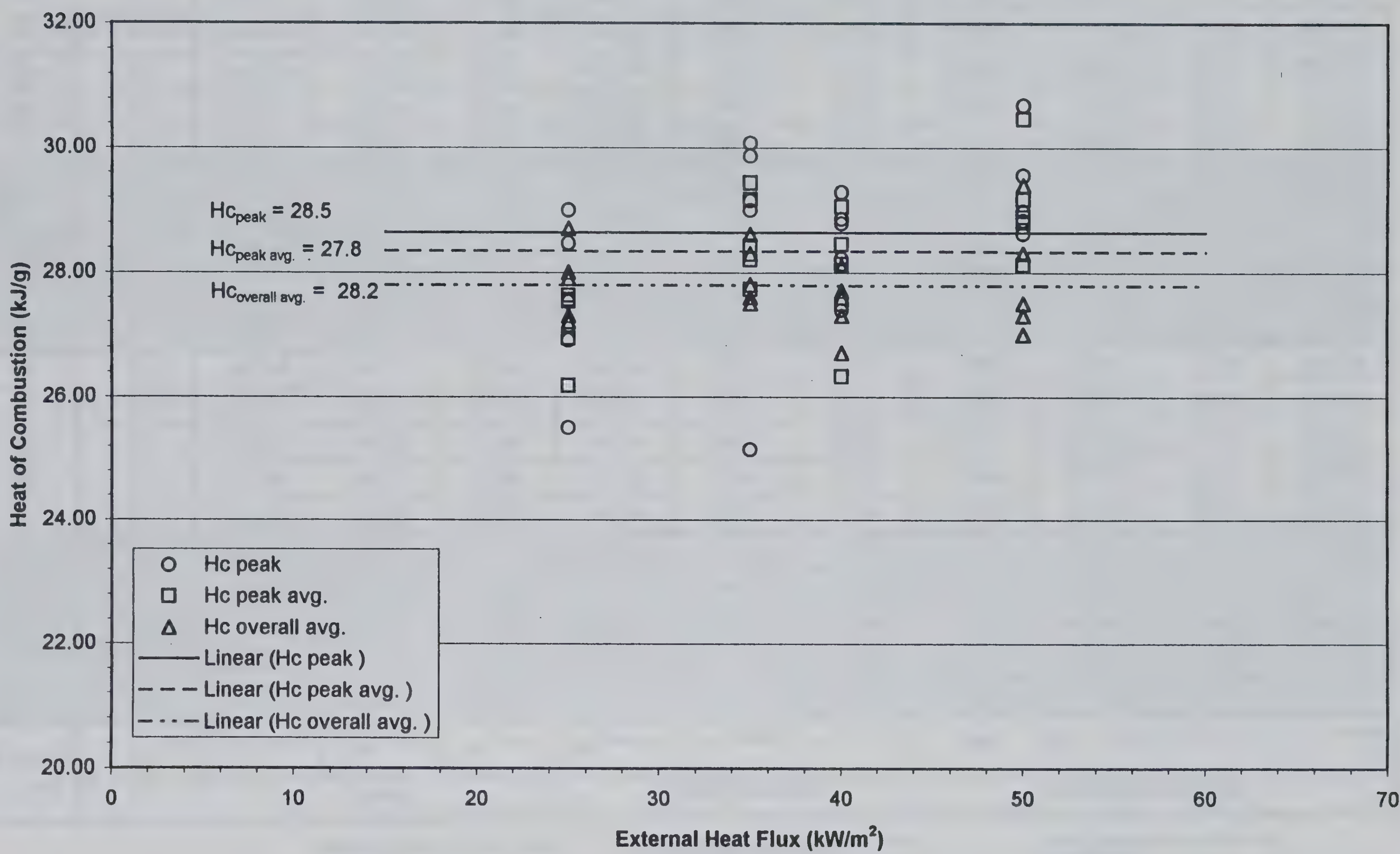
Average of Hc_{peak}	28.5

Average of $Hc_{peak\ avg.}$	28.2

Average of $Hc_{overall\ avg.}$	27.8

q''_{ext} (kW/m^2)	t_{ig} (s)	Peak			Peak Average			Overall Average			
		Q''_{peak}	Hc_{peak}	m''_{peak}	$Q''_{peak\ avg.}$	$Hc_{peak\ avg.}$	$m''_{peak\ avg.}$	-dm/dt	$m''_{overall\ avg.}$	$Hc_{overall\ avg.}$	$Q''_{overall\ avg.}$
25	164	318.87	25.50	12.50	298.12	26.18	11.39	0.0760	8.636	27.3	235.77
25	155	290.98	28.46	10.22	262.07	27.63	9.48	0.0779	8.852	28.0	247.86
25	164	334.65	29.00	11.54	305.88	27.56	11.10	0.0844	9.591	27.9	267.59
25	167	408.31	26.91	15.17	370.35	26.94	13.75	0.1023	11.625	27.2	316.20
25	159	378.85	27.52	13.77	342.56	27.53	12.44	0.0825	9.375	28.7	269.06
35	87	469.99	29.86	15.74	439.81	29.43	14.94	0.1153	13.102	28.6	374.73
35	79	381.14	29.00	13.14	354.31	28.42	12.47	0.0978	11.114	27.6	306.74
35	80	341.36	25.14	13.58	320.06	27.73	11.54	0.0880	10.000	27.5	275.00
35	77	476.77	30.08	15.85	439.45	29.17	15.07	0.1192	13.545	28.3	383.34
35	80	369.70	29.14	12.69	332.71	28.20	11.80	0.0974	11.068	27.8	307.70
40	54	323.13	27.39	11.80	295.66	26.33	11.23	0.0853	9.693	26.7	258.81
40	55	492.75	28.78	17.12	459.62	28.45	16.16	0.1242	14.114	27.7	390.95
40	57	416.18	28.86	14.42	382.93	28.14	13.61	0.0940	10.682	27.6	294.82
40	55	367.56	28.22	13.02	333.25	27.49	12.12	0.0973	11.057	27.3	301.85
40	55	543.06	29.28	18.55	506.77	29.05	17.44	0.1337	15.193	28.1	426.93
50	40	568.65	28.83	19.72	532.07	28.80	18.47	0.1498	17.023	27.5	468.13
50	42	413.66	28.62	14.45	381.25	28.12	13.56	0.1078	12.250	27.0	330.75
50	42	497.12	28.98	17.15	458.54	28.89	15.87	0.1202	13.659	27.3	372.89
50	41	741.62	30.69	24.16	689.11	30.47	22.62	0.1780	20.227	29.4	594.68
50	43	446.67	29.55	15.12	424.10	29.17	14.54	0.1130	12.841	28.3	363.40

4.05 F.R. Extruded Polystyrene Board (40 mm): Heat of Combustion vs. External Heat Flux

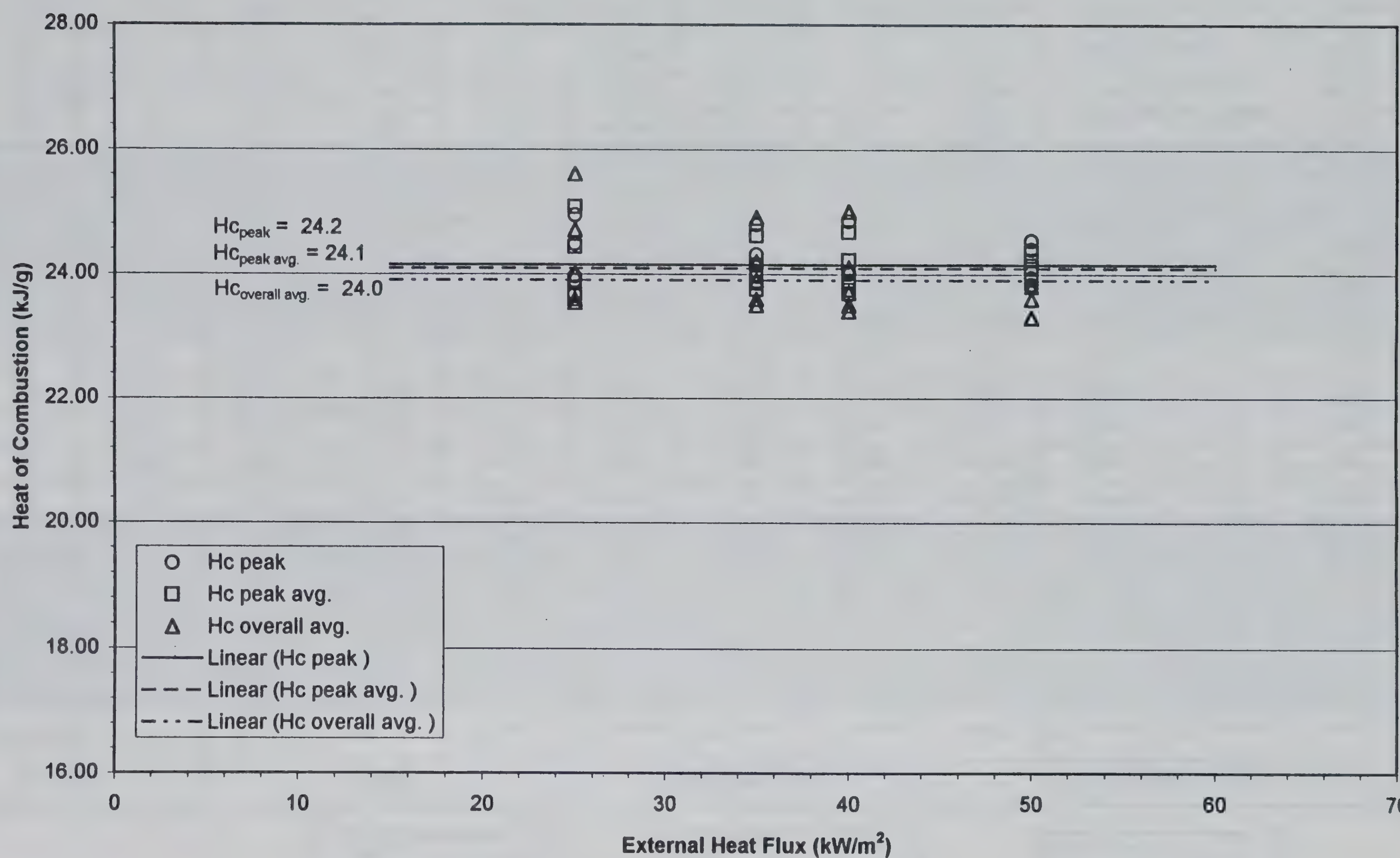


Material: 4.06 Acrylic Glazing

Average of Hc_{peak}	24.2	Average of $Hc_{peak\ avg.}$	24.1
Average of $Hc_{overall\ avg.}$	24.0		

q''_{ext} (kW/m^2)	t_{ig} (s)	Peak			Peak Average			Overall Average			
		Q''_{peak}	Hc_{peak}	m''_{peak}	$Q''_{peak\ avg.}$	$Hc_{peak\ avg.}$	$m''_{peak\ avg.}$	-dmdt	$m''_{overall\ avg.}$	$Hc_{overall\ avg.}$	$Q''_{overall\ avg.}$
25	101	564.81	23.67	23.86	514.84	23.64	21.78	0.1649	18.739	23.5	441.11
25	101	580.28	23.96	24.22	527.85	23.68	22.29	0.1703	19.352	23.6	456.71
25	102	560.96	23.89	23.48	516.99	23.88	21.65	0.1669	18.966	24.0	455.18
25	98	580.29	24.48	23.70	532.13	24.43	21.78	0.1618	18.386	24.7	454.14
25	98	625.55	24.94	25.08	566.17	25.07	22.58	0.1746	19.841	25.6	507.93
35	55	727.17	23.98	30.32	667.34	23.75	28.10	0.2060	23.409	23.5	550.11
35	56	731.20	24.05	30.40	672.37	23.85	28.19	0.2066	23.477	23.6	554.06
35	54	744.76	24.16	30.83	688.44	24.00	28.69	0.2087	23.716	23.9	566.81
35	55	756.87	24.31	31.13	686.39	24.14	28.43	0.2103	23.898	24.2	578.33
35	59	765.19	24.78	30.88	698.18	24.61	28.37	0.2098	23.841	24.9	593.64
40	37	852.70	24.04	35.47	780.83	23.74	32.89	0.2248	25.545	23.5	600.32
40	42	810.75	23.66	34.27	750.53	23.69	31.68	0.2174	24.705	23.4	578.09
40	38	894.53	24.00	37.27	815.34	23.89	34.13	0.2396	27.227	23.7	645.29
40	38	899.29	23.87	37.67	824.20	24.22	34.03	0.2450	27.841	24.1	670.97
40	36	912.50	24.84	36.74	839.16	24.67	34.02	0.2340	26.591	25.0	664.77
50	30	1000.95	23.83	42.00	928.99	24.09	38.56	0.2543	28.898	23.3	673.32
50	32	981.00	23.79	41.24	902.77	24.02	37.58	0.2559	29.080	23.6	686.28
50	32	940.18	23.94	39.27	860.58	23.91	35.99	0.2472	28.091	23.6	662.95
50	31	994.99	24.39	40.79	905.06	24.22	37.37	0.2292	26.045	23.6	614.67
50	31	1022.13	24.53	41.67	936.47	24.34	38.47	0.2453	27.875	23.8	663.43

4.06 Acrylic Glazing: Heat of Combustion vs. External Heat Flux



Material: 4.07 F.R. PVC

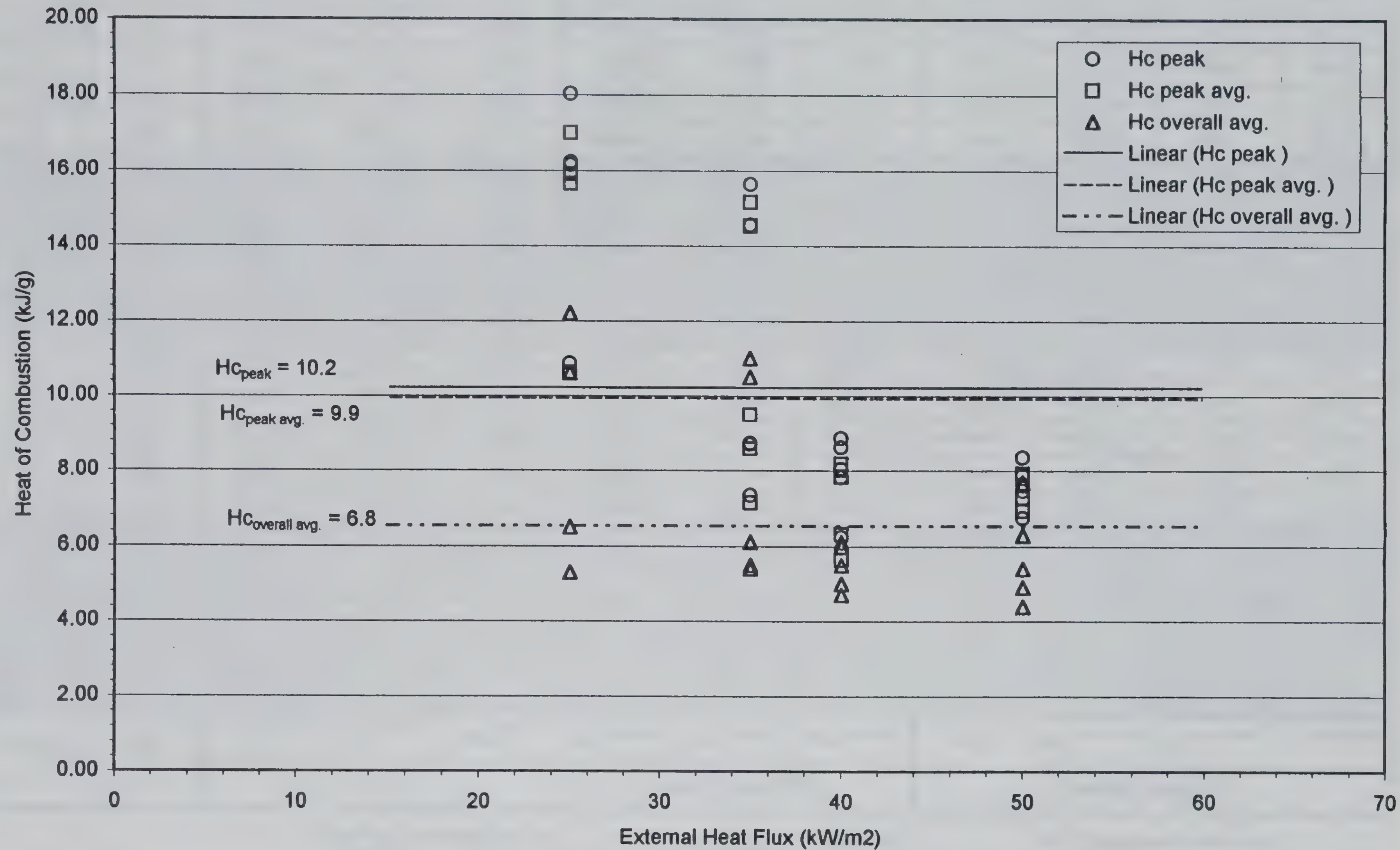
Average of Hc_{peak}	10.2

Average of $Hc_{peak\ avg.}$	9.9

Average of $Hc_{overall\ avg.}$	6.8

q''_{ext} (kW/m^2)	t_{ig} (s)	Peak			Peak Average			Overall Average			
		Q''_{peak}	Hc_{peak}	m''_{peak}	$Q''_{peak\ avg.}$	$Hc_{peak\ avg.}$	$m''_{peak\ avg.}$	-dmdt	$m''_{overall\ avg.}$	$Hc_{overall\ avg.}$	$Q''_{overall\ avg.}$
25	518	125.33	18.03	6.95	112.69	16.99	6.63	0.0405	4.602	10.6	48.78
25	164	111.48	16.22	6.87	103.69	15.90	6.52	0.0433	4.920	5.3	26.08
25											
25	281	151.13	10.86	13.91	143.93	10.62	13.55	0.0410	4.659	6.5	30.28
25	589	143.40	16.15	8.88	135.12	15.65	8.63	0.0571	6.489	12.2	79.16
35	234	109.10	7.35	14.84	103.02	7.14	14.43	0.0770	8.750	6.1	53.38
35	209	58.13	8.70	6.68	53.11	9.49	5.60	0.0764	8.682	5.4	46.88
35	342	154.05	14.56	10.58	146.16	14.53	10.06	0.0706	8.023	11.0	88.25
35	335	109.55	15.63	7.01	101.32	15.15	6.69	0.0628	7.136	10.5	74.93
35	185	120.08	8.73	13.75	113.36	8.59	13.20	0.0840	9.545	5.5	52.50
40	77	149.36	8.05	18.55	134.83	7.83	17.22	0.1031	11.716	6.1	71.47
40	81	114.03	7.81	14.60	101.75	6.32	16.10	0.1070	12.159	5.0	60.80
40	88	155.62	8.87	17.54	144.23	8.18	17.63	0.1085	12.330	6.0	73.98
40	85	142.85	8.63	16.55	132.22	8.02	16.49	0.1022	11.614	5.5	63.88
40	99	106.36	6.24	17.04	93.91	5.63	16.68	0.0971	11.034	4.7	51.86
50	78	154.72	7.46	20.74	140.55	7.27	19.33	0.1289	14.648	4.9	71.77
50	53	148.96	6.75	22.07	132.55	6.94	19.10	0.1389	15.784	5.4	85.23
50	54	147.14	8.35	17.62	136.06	7.93	17.16	0.1219	13.852	6.3	87.27
50	72	141.94	7.65	18.55	141.81	7.29	19.45	0.1386	15.750	4.4	69.30
50	59	175.79	7.89	22.28	159.98	7.92	20.20	0.1440	16.364	7.7	126.00

4.07 F.R. PVC: Heat of Combustion vs. External Heat Flux

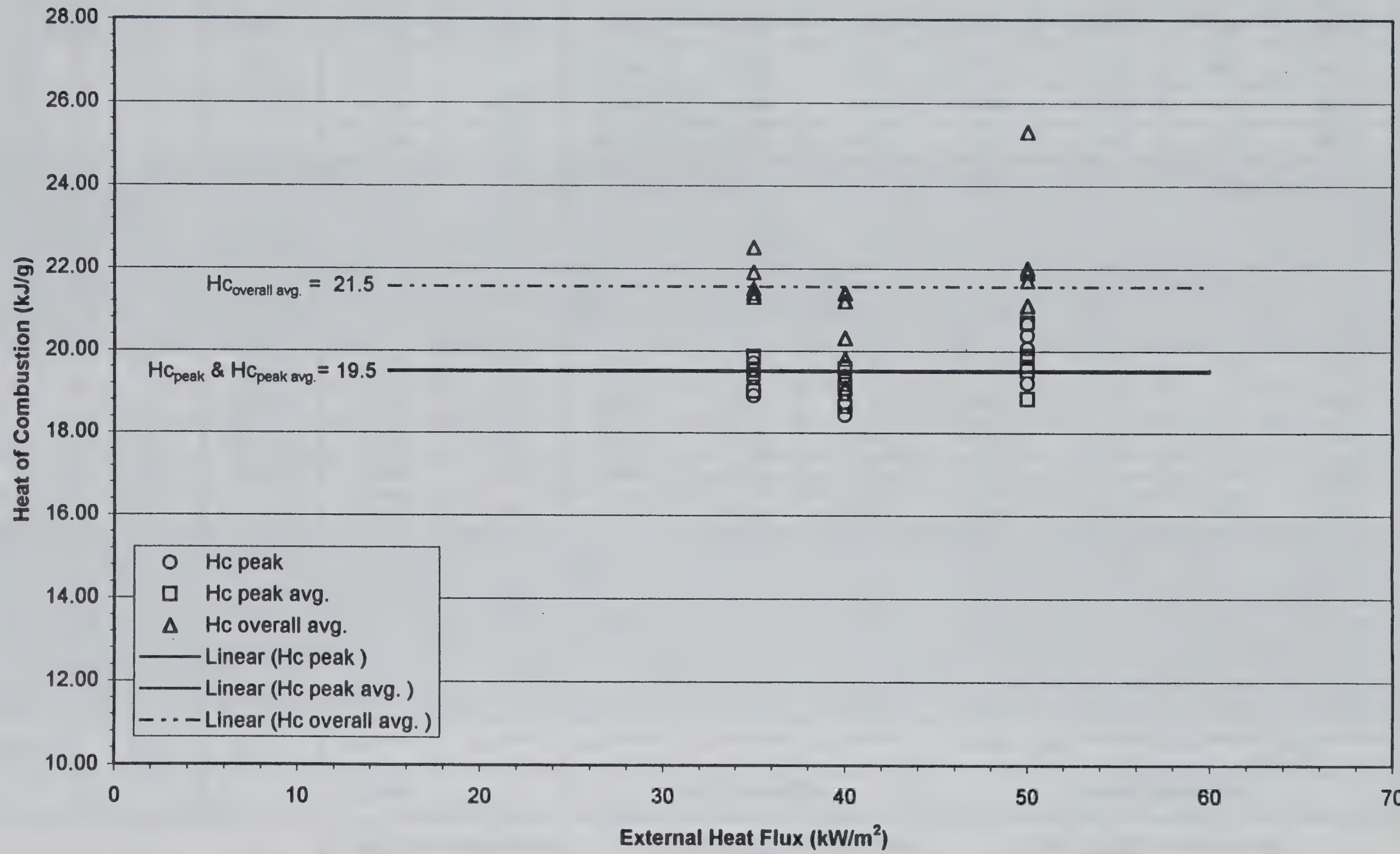


Material: 4.08 3-Layered F.R. Polycarbonate Panel

Average of Hc_{peak}	19.5
Average of $Hc_{peak\ avg.}$	19.5
Average of $Hc_{overall\ avg.}$	21.5

q''_{ext} (kW/m^2)	t_{ig} (s)	Peak			Peak Average			Overall Average			
		Q''_{peak}	Hc_{peak}	m''_{peak}	$Q''_{peak\ avg.}$	$Hc_{peak\ avg.}$	$m''_{peak\ avg.}$	-dmdt	$m''_{overall\ avg.}$	$Hc_{overall\ avg.}$	$Q''_{overall\ avg.}$
25											
25											
25											
25											
25											
35	285	617.65	19.32	31.97	576.81	19.42	29.70	0.1973	22.420	21.3	477.56
35	287	597.73	19.54	30.59	527.74	19.01	27.76	0.1634	18.568	21.5	399.22
35	225	552.76	19.70	28.06	512.76	19.86	25.82	0.1432	16.273	22.5	366.14
35	300	650.45	18.90	34.42	631.90	19.50	32.41	0.1564	17.773	21.4	380.34
35	220	597.63	19.34	30.90	539.06	19.81	27.21	0.1710	19.432	21.9	425.56
40	165	606.09	19.62	30.89	569.36	19.17	29.70	0.1722	19.568	19.1	373.75
40	144	514.73	18.44	27.91	475.20	18.65	25.48	0.1778	20.205	20.3	410.15
40	157	537.51	18.75	28.67	484.90	19.33	25.09	0.1216	13.818	19.8	273.60
40	167	494.12	19.38	25.50	460.89	19.19	24.02	0.1580	17.955	21.2	380.64
40	164	546.61	18.96	28.83	505.72	19.57	25.84	0.1466	16.659	21.4	356.50
50	102	737.77	20.64	35.74	689.45	20.70	33.31	0.1818	20.659	25.3	522.68
50	101	601.67	19.21	31.32	560.46	18.83	29.76	0.1915	21.761	21.1	459.16
50	102	733.15	19.82	36.99	701.49	19.63	35.74	0.1929	21.920	21.9	480.06
50	97	712.74	20.05	35.55	658.00	19.51	33.73	0.1978	22.477	21.7	487.76
50	104	597.88	20.38	29.34	537.51	19.89	27.02	0.1859	21.125	22.0	464.75

4.08 3-Layered F.R. Polycarbonate Panel: Heat of Combustion vs. External Heat Flux



Material: 4.09 Varnished Massive Timber

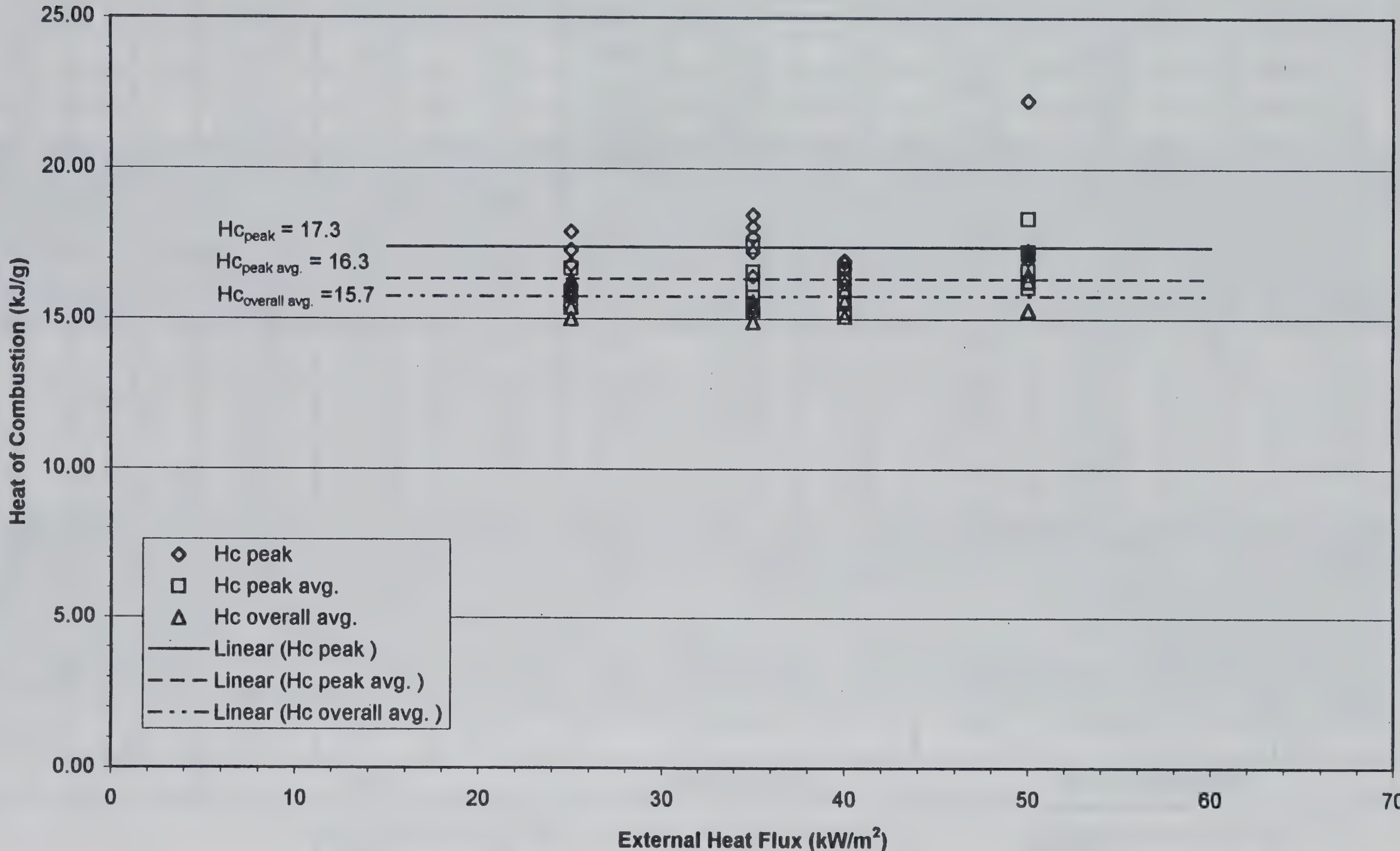
Average of Hc_{peak}	17.3

Average of $Hc_{peak\ avg.}$	16.3

Average of $Hc_{overall\ avg.}$	15.7

q''_{ext} (kW/m^2)	t_{ig} (s)	Peak			Peak Average			Overall Average			
		Q''_{peak}	Hc_{peak}	m''_{peak}	$Q''_{peak\ avg.}$	$Hc_{peak\ avg.}$	$m''_{peak\ avg.}$	-dmdt	$m''_{overall\ avg.}$	$Hc_{overall\ avg.}$	$Q''_{overall\ avg.}$
25	73	242.65	16.11	15.06	221.02	15.36	14.39	0.0694	7.886	16.3	128.55
25	65	253.66	16.84	15.06	232.06	15.76	14.72	0.0592	6.727	15.4	103.60
25	73	254.92	15.70	16.24	252.95	15.93	15.88	0.0647	7.352	16.0	117.64
25	65	266.43	17.92	14.87	248.78	16.69	14.91	0.0655	7.443	16.2	120.58
25	75	267.62	17.31	15.46	241.02	15.84	15.22	0.0615	6.989	15.0	104.83
35	35	274.54	17.25	15.92	250.87	15.76	15.92	0.0784	8.909	14.9	132.75
35	34	269.95	18.09	14.92	238.45	16.60	14.36	0.0783	8.898	15.4	137.03
35	33	277.86	18.48	15.04	250.94	17.42	14.41	0.0775	8.807	15.5	136.51
35	32	264.52	17.75	14.90	245.90	16.16	15.22	0.0810	9.205	15.3	140.83
35	32	253.49	16.44	15.42	236.97	15.46	15.33	0.0734	8.341	15.6	130.12
40	22	255.28	16.97	15.04	236.73	15.52	15.25	0.0881	10.011	15.1	151.17
40	23	256.75	16.38	15.67	237.40	16.38	14.49	0.0876	9.955	15.6	155.29
40	26	278.16	16.71	16.65	278.16	16.71	16.65	0.0870	9.886	16.0	158.18
40	23	249.88	16.20	15.42	236.27	15.23	15.51	0.0880	10.000	16.0	160.00
40	22	252.60	16.92	14.93	234.94	16.02	14.67	0.0840	9.545	15.6	148.91
50	15	288.78	17.19	16.80	269.95	16.07	16.80	0.0974	11.068	15.3	169.34
50	11	284.86	17.20	16.56	270.47	17.25	15.68	0.0984	11.182	16.3	182.26
50	11	286.79	22.28	12.87	273.81	18.37	14.91	0.0971	11.034	16.5	182.06
50	15	265.49	17.30	15.35	253.66	16.23	15.63	0.0911	10.352	16.3	168.74
50	14	267.28	17.04	15.69	248.77	16.65	14.94	0.0918	10.432	16.3	170.04

4.09 Varnished Massive Timber: Heat of Combustion vs. External Heat Flux



Material: 4.10 F.R. Plywood

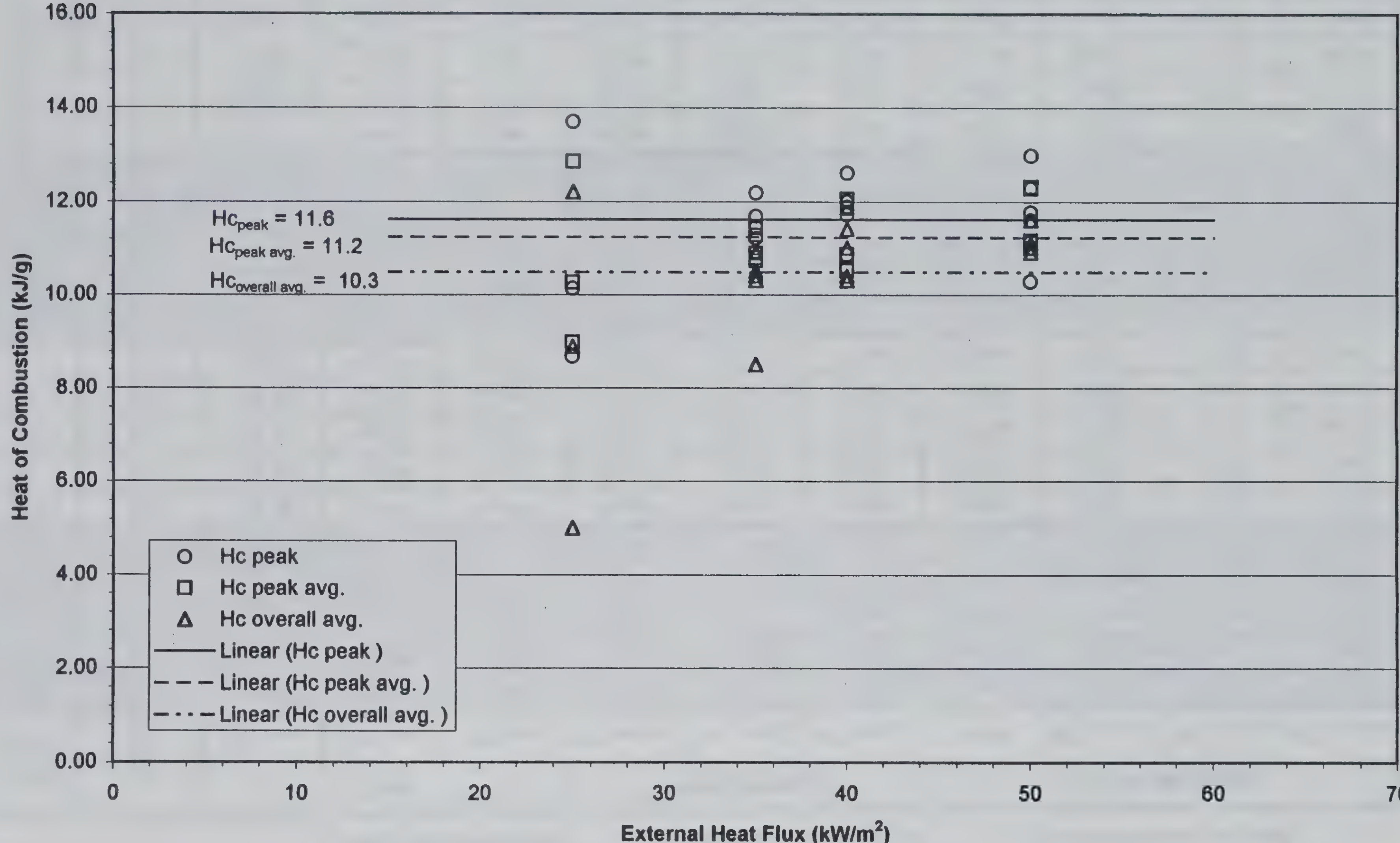
Average of Hc_{peak}	11.5

Average of $Hc_{peak\ avg.}$	11.2

Average of $Hc_{overall\ avg.}$	10.3

q''_{ext} (kW/m^2)	t_{ig} (s)	Peak			Peak Average			Overall Average			
		Q''_{peak}	Hc_{peak}	m''_{peak}	$Q''_{peak\ avg.}$	$Hc_{peak\ avg.}$	$m''_{peak\ avg.}$	-dmdt	$m''_{overall\ avg.}$	$Hc_{overall\ avg.}$	$Q''_{overall\ avg.}$
25	536	102.46	13.70	7.48	91.44	12.85	7.12	0.0542	6.159	12.2	75.14
25											
25											
25	305	71.71	10.13	7.08	66.09	10.26	6.44	0.0466	5.295	8.9	47.13
25	71	94.35	8.68	10.87	87.25	8.98	9.72	0.0429	4.875	5.0	24.38
35	16	111.94	11.68	9.58	102.85	11.43	9.00	0.0552	6.273	8.5	53.32
35	11	100.17	12.18	8.22	91.12	11.27	8.09	0.0562	6.386	10.9	69.61
35	10	99.88	11.21	8.91	91.97	10.78	8.53	0.0535	6.080	10.4	63.23
35	9	108.77	11.45	9.50	100.62	10.88	9.25	0.0520	5.909	10.3	60.86
35	13	93.99	10.91	8.62	86.91	10.72	8.11	0.0549	6.239	10.5	65.51
40	7	104.44	11.88	8.79	93.82	10.86	8.64	0.0629	7.148	11.0	78.63
40	15	118.70	12.61	9.41	110.78	11.85	9.35	0.0628	7.136	11.4	81.35
40	7	110.71	11.99	9.23	103.26	10.51	9.82	0.0610	6.932	10.3	71.40
40	9	101.86	10.85	9.39	92.70	10.54	8.80	0.0611	6.943	10.3	71.51
40	8	136.22	11.71	11.63	130.18	12.05	10.80	0.0595	6.761	10.4	70.32
50	5	115.20	11.76	9.80	106.45	11.11	9.58	0.0627	7.125	10.9	77.66
50	5	114.41	11.60	9.86	103.02	11.00	9.37	0.0625	7.102	10.9	77.41
50	6	112.09	10.28	10.90	104.86	11.17	9.39	0.0606	6.886	11.0	75.75
50	6	139.98	12.98	10.78	126.44	12.28	10.30	0.0628	7.136	11.1	79.21
50	6	126.84	12.28	10.33	115.44	12.31	9.38	0.0605	6.875	11.6	79.75

4.10 F.R. Plywood: Heat of Combustion vs. External Heat Flux

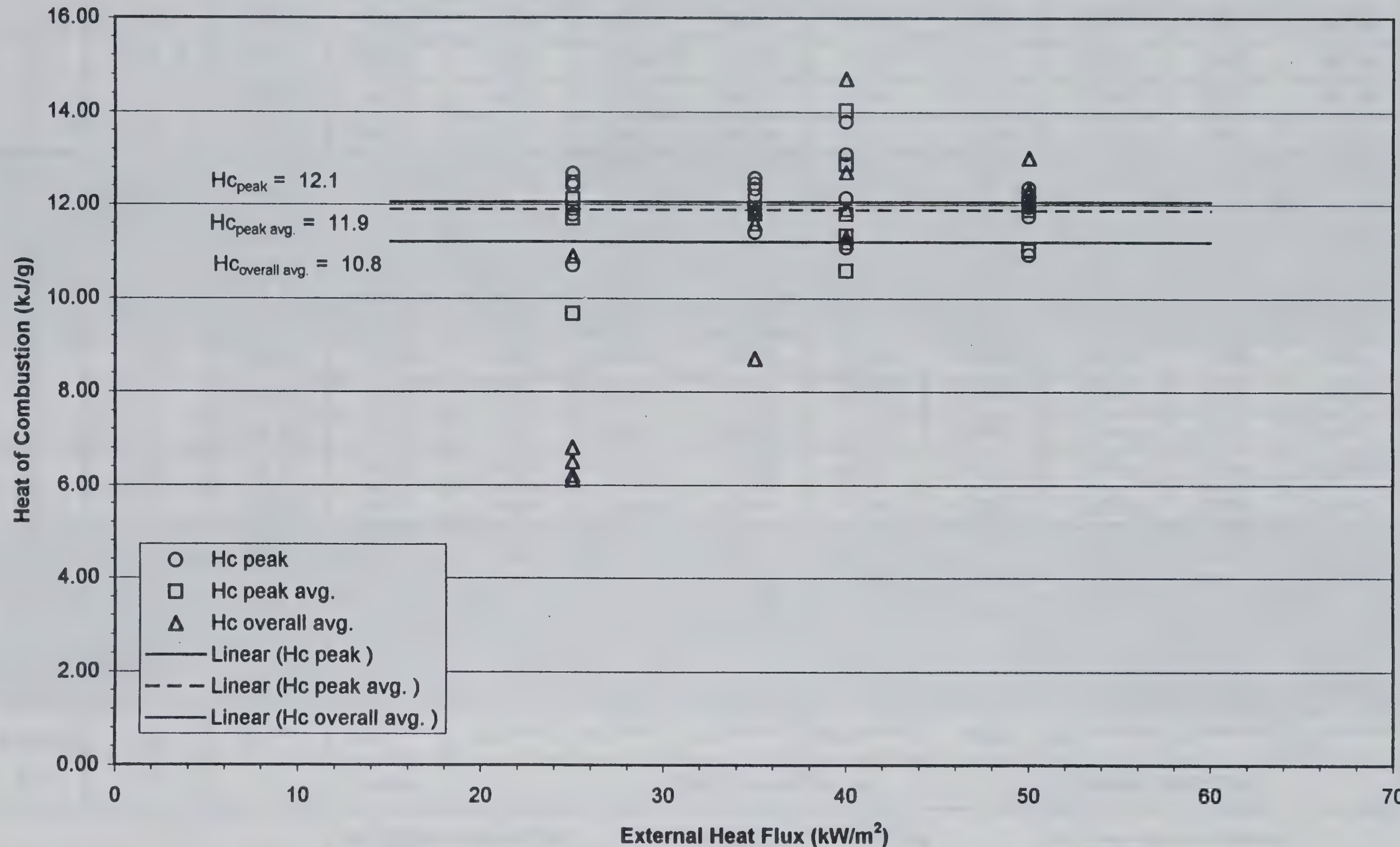


Material: 4.11 Normal Plywood

Average of Hc_{peak}	12.1
Average of $Hc_{peak\ avg.}$	11.9
Average of $Hc_{overall\ avg.}$	10.8

q''_{ext} (kW/m^2)	t_{ig} (s)	Peak			Peak Average			Overall Average			
		Q''_{peak}	Hc_{peak}	m''_{peak}	$Q''_{peak\ avg.}$	$Hc_{peak\ avg.}$	$m''_{peak\ avg.}$	-dmdt	$m''_{overall\ avg.}$	$Hc_{overall\ avg.}$	$Q''_{overall\ avg.}$
25	78	122.58	10.70	11.46	111.52	9.67	11.53	0.0530	6.023	6.5	39.15
25	65	147.63	12.48	11.83	147.63	12.48	11.83	0.0526	5.977	6.1	36.46
25	74	147.67	11.78	12.54	134.27	11.70	11.48	0.0545	6.193	10.9	67.51
25	65	178.93	12.67	14.12	161.39	12.11	13.33	0.0503	5.716	6.2	35.44
25	67	171.72	12.40	13.85	155.44	11.90	13.06	0.0524	5.955	6.8	40.49
35	37	183.26	11.41	16.06	169.36	11.83	14.32	0.0674	7.659	11.8	90.38
35	33	179.55	12.34	14.55	163.85	11.79	13.90	0.0648	7.364	11.6	85.42
35	32	153.25	12.19	12.57	140.81	11.91	11.82	0.0669	7.602	11.6	88.19
35	32	151.58	12.45	12.18	141.72	11.90	11.91	0.0665	7.557	8.7	65.74
35	37	180.33	12.57	14.35	167.73	11.93	14.06	0.0635	7.216	11.9	85.87
40	19	159.75	13.08	12.21	148.47	12.87	11.54	0.0716	8.136	12.7	103.33
40	18	215.30	13.79	15.61	194.89	14.03	13.89	0.0740	8.409	14.7	123.61
40	24	153.32	11.10	13.81	143.65	11.33	12.68	0.0731	8.307	11.2	93.04
40	23	190.81	12.13	15.73	176.95	11.79	15.01	0.0727	8.261	11.3	93.35
40	22	196.89	11.08	17.77	175.12	10.58	16.55	0.0756	8.591	11.9	102.23
50	14	173.15	10.93	15.84	161.53	11.03	14.64	0.0770	8.750	12.1	105.88
50	16	196.23	11.75	16.70	183.24	11.88	15.42	0.0828	9.409	12.0	112.91
50	16	191.68	12.35	15.52	191.68	12.10	15.84	0.0794	9.023	12.1	109.18
50	15	206.88	11.95	17.31	190.78	12.19	15.65	0.0831	9.443	13.0	122.76
50	18	196.40	12.16	16.15	181.98	12.03	15.13	0.0797	9.057	12.3	111.40

4.11 Normal Plywood: Heat of Combustion vs. External Heat Flux



Material: 4.20 F.R. Expanded Polystyrene Board (40 mm)

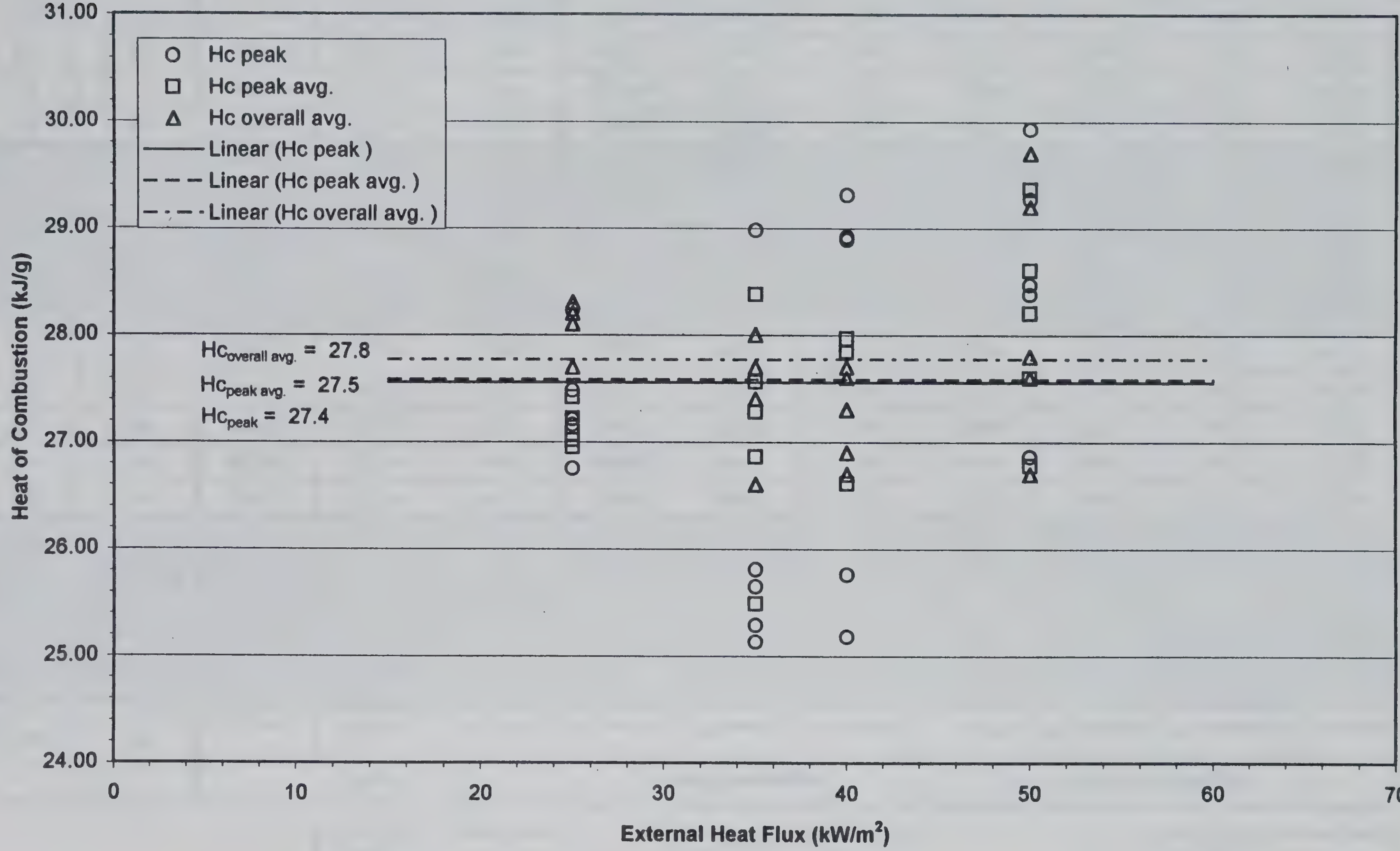
Average of Hc_{peak}	27.4

Average of $Hc_{peak\ avg.}$	27.5

Average of $Hc_{overall\ avg.}$	27.8

q''_{ext} (kW/m^2)	t_{ig} (s)	Peak			Peak Average			Overall Average			
		Q''_{peak}	Hc_{peak}	m''_{peak}	$Q''_{peak\ avg.}$	$Hc_{peak\ avg.}$	$m''_{peak\ avg.}$	-dmdt	$m''_{overall\ avg.}$	$Hc_{overall\ avg.}$	$Q''_{overall\ avg.}$
25	145	300.68	28.23	10.65	272.22	26.95	10.10	0.0884	10.045	27.7	278.26
25	168	333.58	26.75	12.47	304.45	27.42	11.10	0.0958	10.886	28.2	307.00
25	153	362.04	27.48	13.17	327.18	27.22	12.02	0.0985	11.193	28.1	314.53
25	177	311.72	27.21	11.46	291.87	27.13	10.76	0.0865	9.830	28.3	278.18
25	175	369.19	27.16	13.59	335.15	27.02	12.40	0.0984	11.182	28.2	315.33
35	70	343.99	25.13	13.69	306.86	25.49	12.04	0.0931	10.580	26.6	281.42
35	68	346.71	25.29	13.71	312.77	27.56	11.35	0.0879	9.989	27.4	273.69
35	67	326.37	25.81	12.65	298.32	26.86	11.11	0.0862	9.795	28.0	274.27
35	71	327.56	25.65	12.77	285.45	27.28	10.46	0.0846	9.614	27.7	266.30
35	65	370.44	28.98	12.78	341.39	28.38	12.03	0.0908	10.318	28.0	288.91
40	61	394.46	29.31	13.46	365.27	27.84	13.12	0.1091	12.398	26.9	333.50
40	60	372.65	28.92	12.89	345.80	27.97	12.36	0.1067	12.125	27.3	331.01
40	52	311.91	25.76	12.11	285.51	26.61	10.73	0.0898	10.205	26.7	272.46
40	59	335.99	28.89	11.63	312.04	27.84	11.21	0.0972	11.045	27.7	305.96
40	55	372.36	25.18	14.79	338.56	27.85	12.16	0.0946	10.750	27.6	296.70
50	36	387.15	26.86	14.41	350.07	26.78	13.07	0.1030	11.705	26.7	312.51
50	39	424.32	28.38	14.95	397.27	28.20	14.09	0.1131	12.852	27.8	357.29
50	38	411.56	28.47	14.46	379.66	27.60	13.76	0.1131	12.852	27.6	354.72
50	39	456.74	29.27	15.60	414.28	28.61	14.48	0.1102	12.523	29.2	365.66
50	41	485.19	29.93	16.21	460.44	29.36	15.68	0.1168	13.273	29.7	394.20

4.20 F.R. Exp. Polystyrene Board (40 mm): Heat of Combustion vs. External Heat Flux

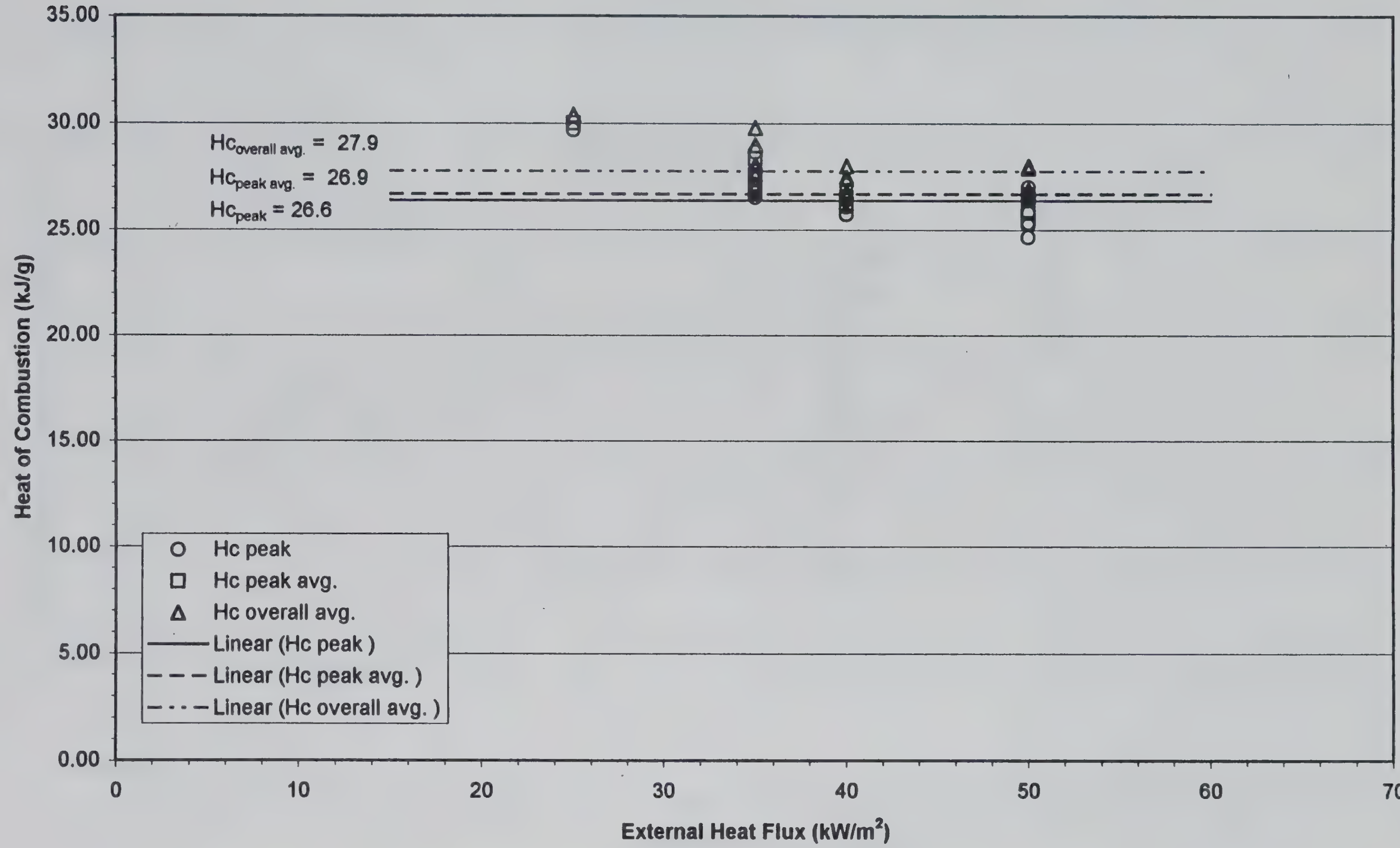


Material: 4.21 F.R. Expanded Polystyrene Board (80 mm)

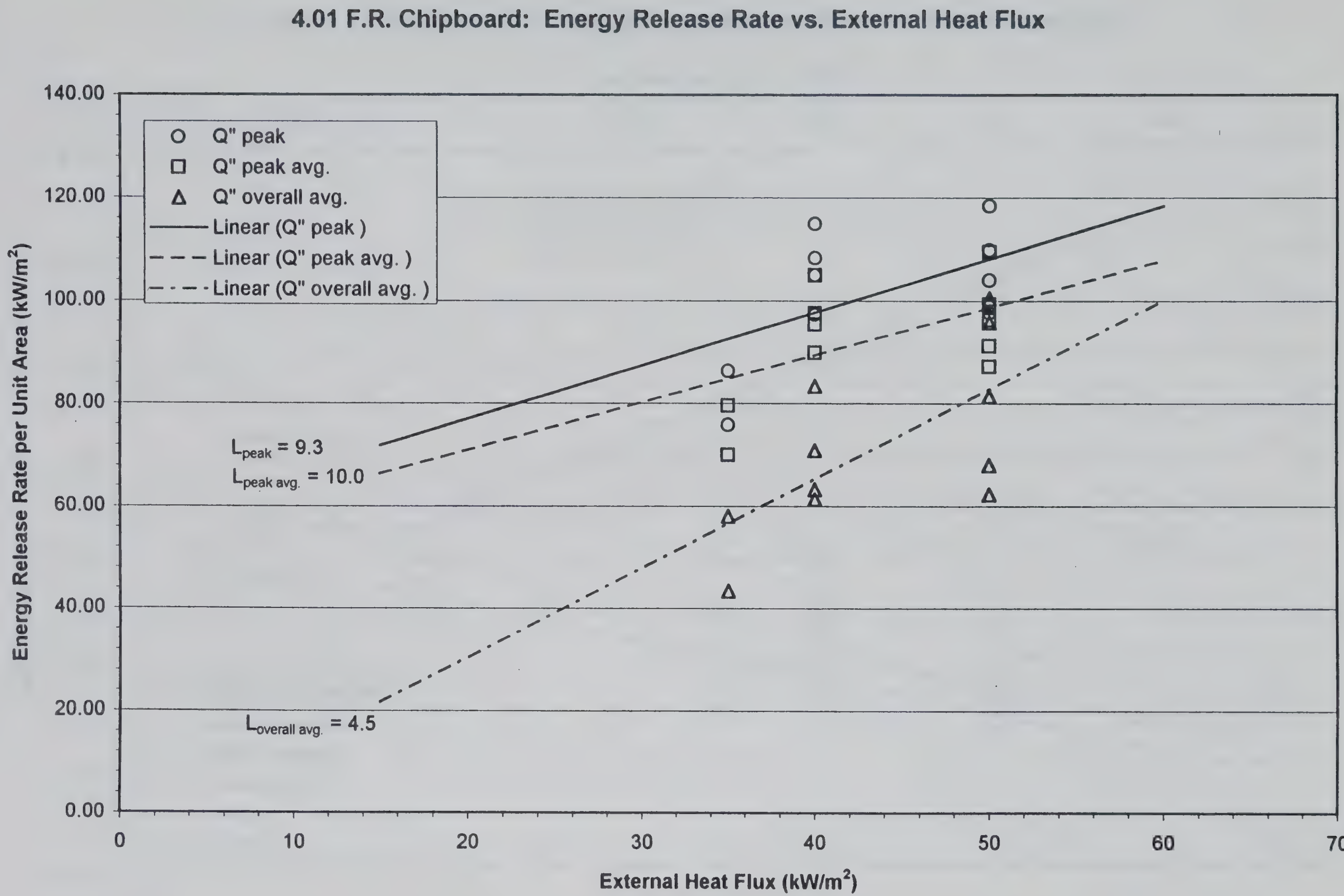
Average of Hc_{peak}	26.6
Average of $Hc_{peak\ avg.}$	26.8
Average of $Hc_{overall\ avg.}$	27.9

q''_{ext} (kW/m^2)	t_{ig} (s)	Peak			Peak Average			Overall Average			
		Q''_{peak}	Hc_{peak}	m''_{peak}	$Q''_{peak\ avg.}$	$Hc_{peak\ avg.}$	$m''_{peak\ avg.}$	-dmdt	$m''_{overall\ avg.}$	$Hc_{overall\ avg.}$	$Q''_{overall\ avg.}$
25											
25											
25											
25	590	239.13	29.70	8.05	214.76	30.01	7.16	0.0510	5.795	30.4	176.18
25											
35	79	291.08	27.14	10.73	260.97	26.85	9.72	0.0751	8.534	27.6	235.54
35	108	292.44	26.74	10.94	268.42	27.39	9.80	0.0798	9.068	28.1	254.82
35	68	283.12	27.16	10.42	266.53	27.09	9.84	0.0806	9.159	28.0	256.45
35	70	298.63	26.53	11.26	278.92	27.63	10.09	0.0751	8.534	29.0	247.49
35	118	260.78	28.68	9.09	238.58	28.37	8.41	0.0654	7.432	29.8	221.47
40	56	322.10	25.72	12.52	296.76	26.26	11.30	0.0740	8.409	27.5	231.25
40	57	343.90	26.06	13.20	321.67	26.14	12.31	0.1019	11.580	26.8	310.33
40	61	317.90	25.73	12.36	290.51	26.14	11.11	0.0897	10.193	27.5	280.31
40	61	319.59	27.12	11.78	290.14	26.50	10.95	0.0787	8.943	28.0	250.41
40	56	323.23	26.40	12.24	294.81	26.54	11.11	0.0900	10.227	27.4	280.23
50	38	286.42	25.32	11.31	266.60	25.79	10.34	0.0751	8.534	26.8	228.71
50	37	288.36	27.03	10.67	270.80	26.37	10.27	0.0892	10.136	26.6	269.63
50	44	336.45	25.23	13.34	312.77	25.82	12.11	0.1064	12.091	26.9	325.25
50	36	317.35	24.64	12.88	292.38	25.93	11.28	0.0841	9.557	27.9	266.64
50	35	311.51	25.80	12.07	292.63	26.69	10.96	0.0910	10.341	28.0	289.55

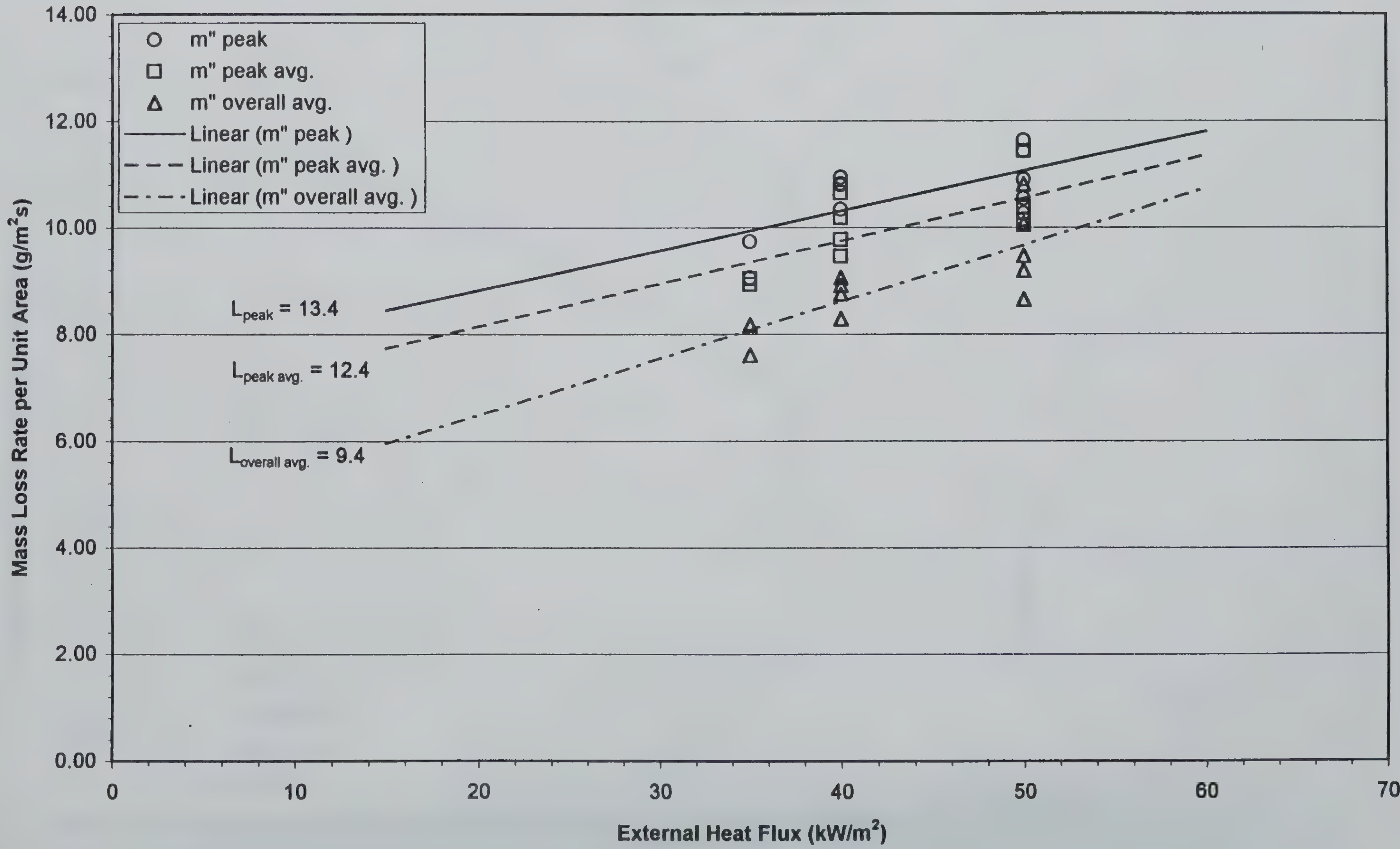
4.21 F.R. Exp. Polystyrene Board (80 mm): Heat of Combustion vs. External Heat Flux



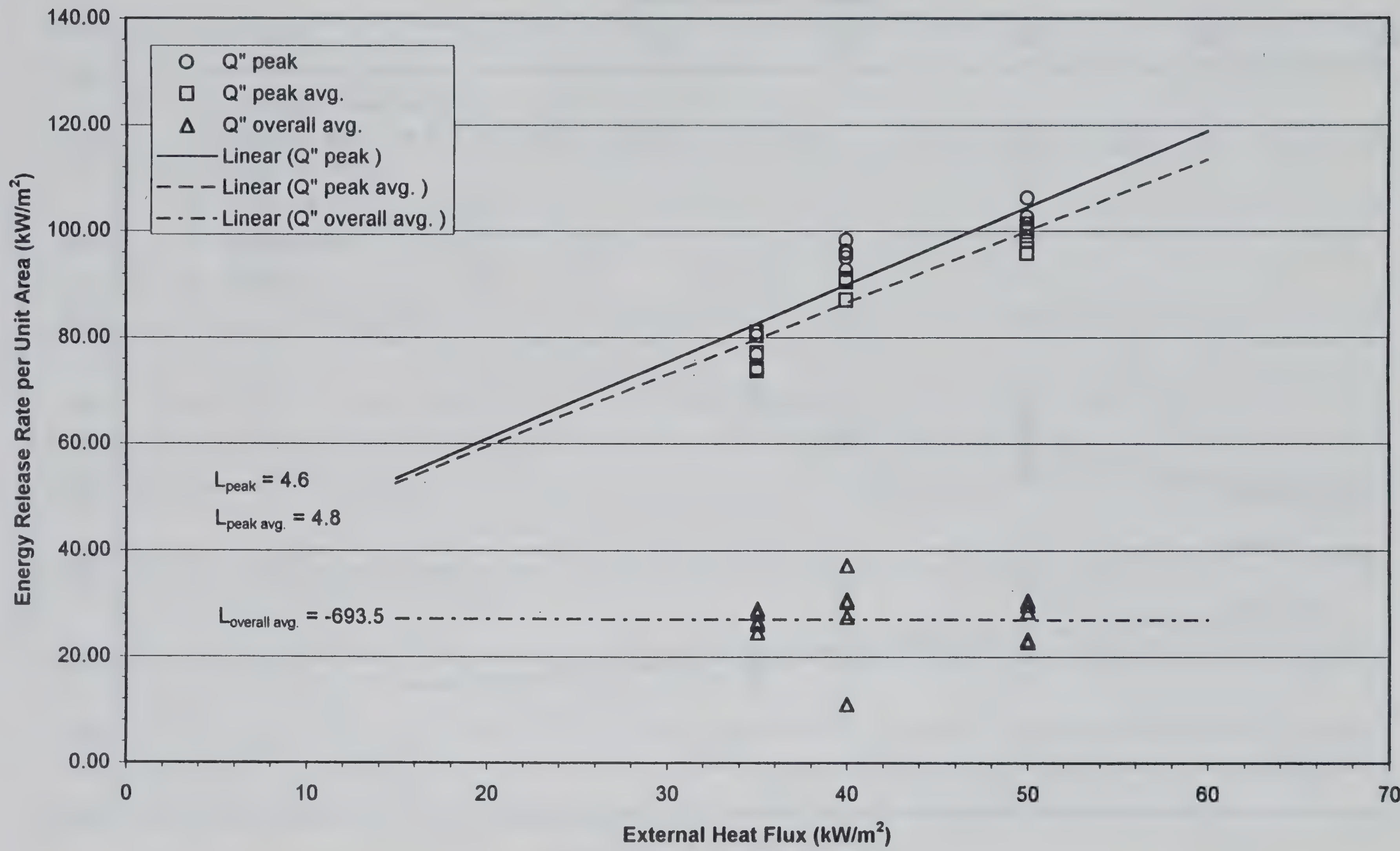
A.5 – Heat of Gasification Data


4.01 F.R. Chipboard: Energy Release Rate vs. External Heat Flux
Q" peak
Q" peak avg.
Q" overall avg.
Linear (Q" peak)
Linear (Q" peak avg.)
Linear (Q" overall avg.)
L_{peak} = 9.3
$L_{peak\ avg.}$ = 10.0
$L_{overall\ avg.}$ = 4.5
Energy Release Rate per Unit Area (kW/m^2)
External Heat Flux (kW/m^2)
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
0
10
20
30
40
50
60
70

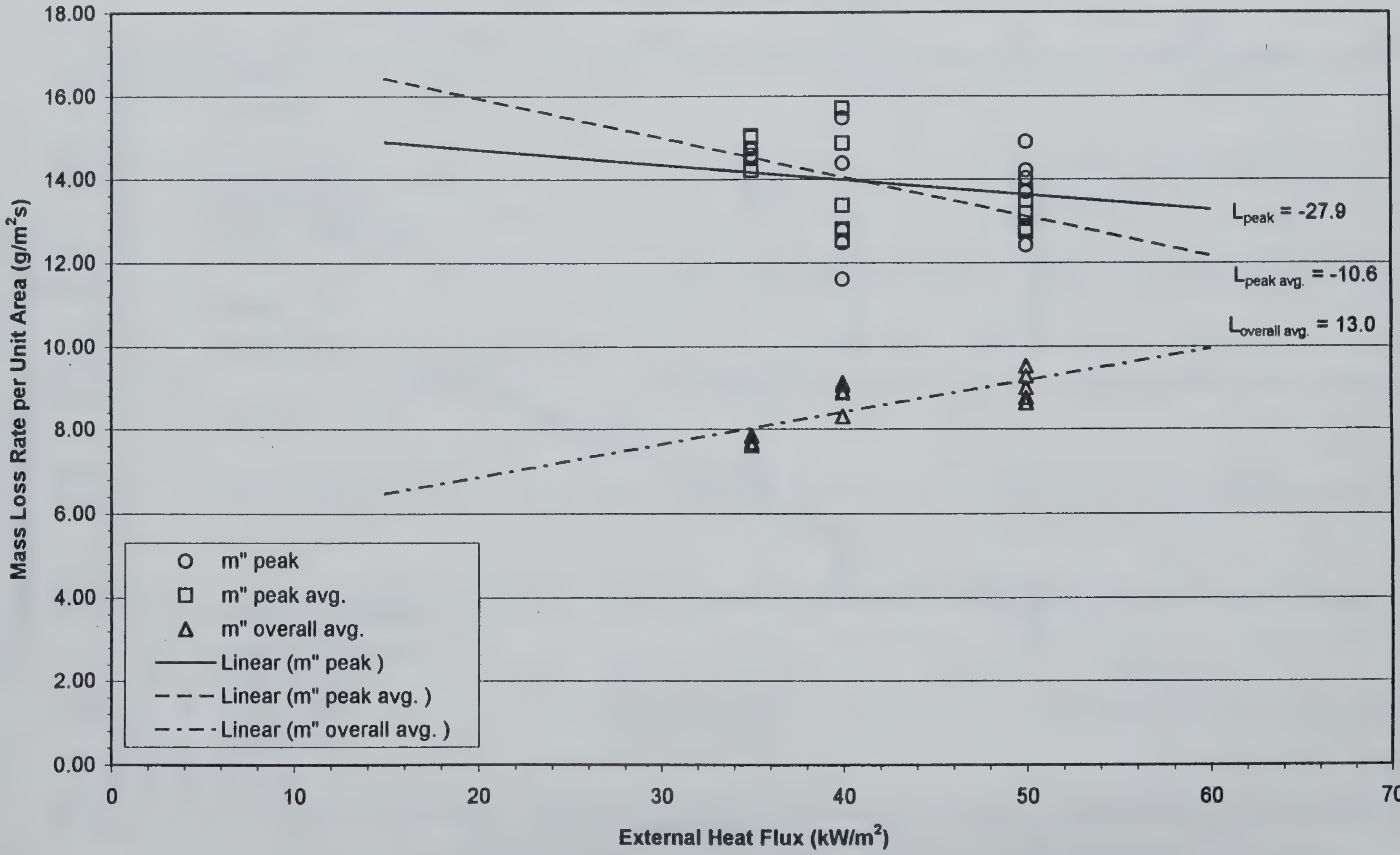
4.01 F.R. Chipboard: Mass Loss Rate vs. External Heat Flux



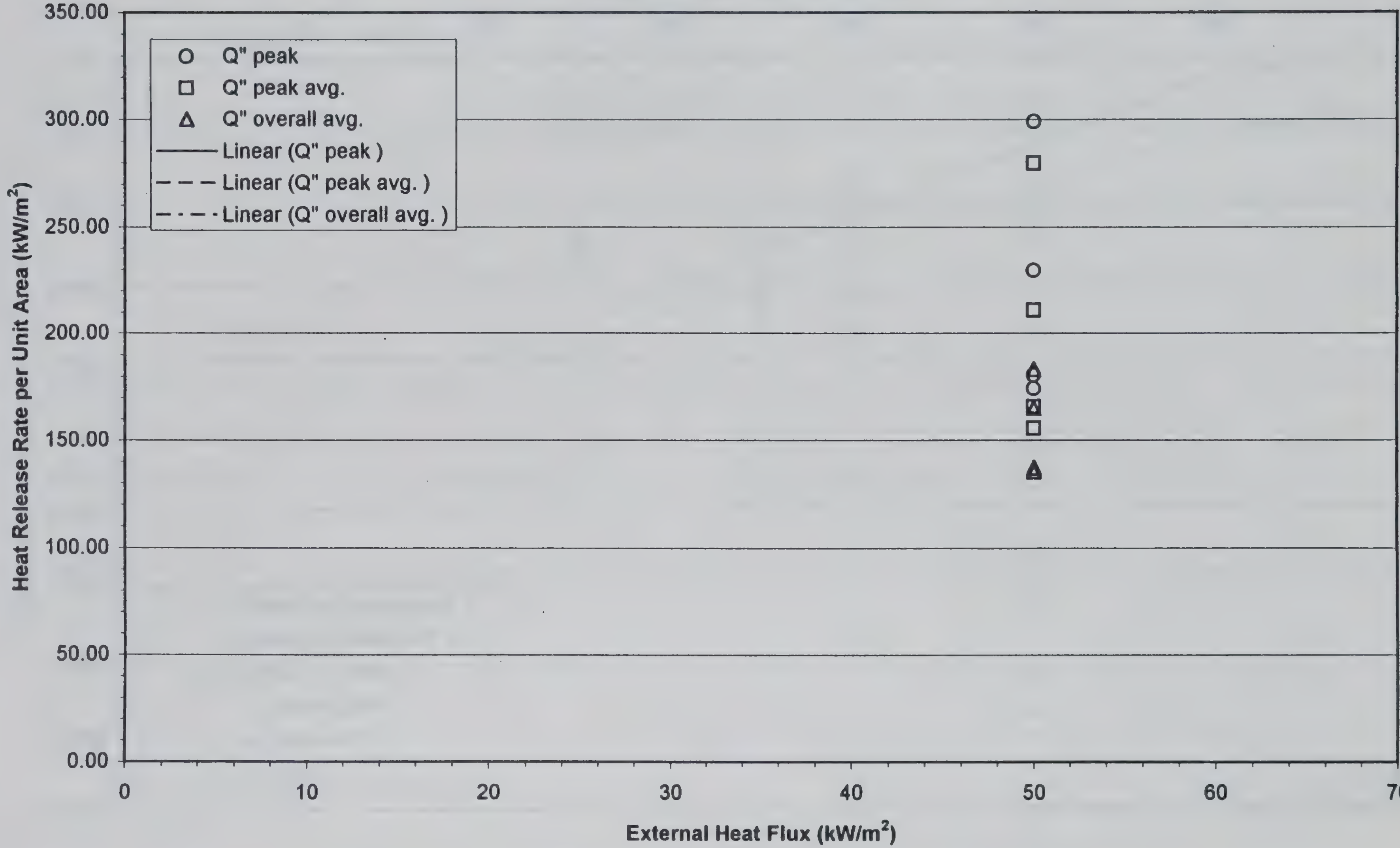
4.02 Paper Faced Gypsum Board: Energy Release Rate vs. External Heat Flux



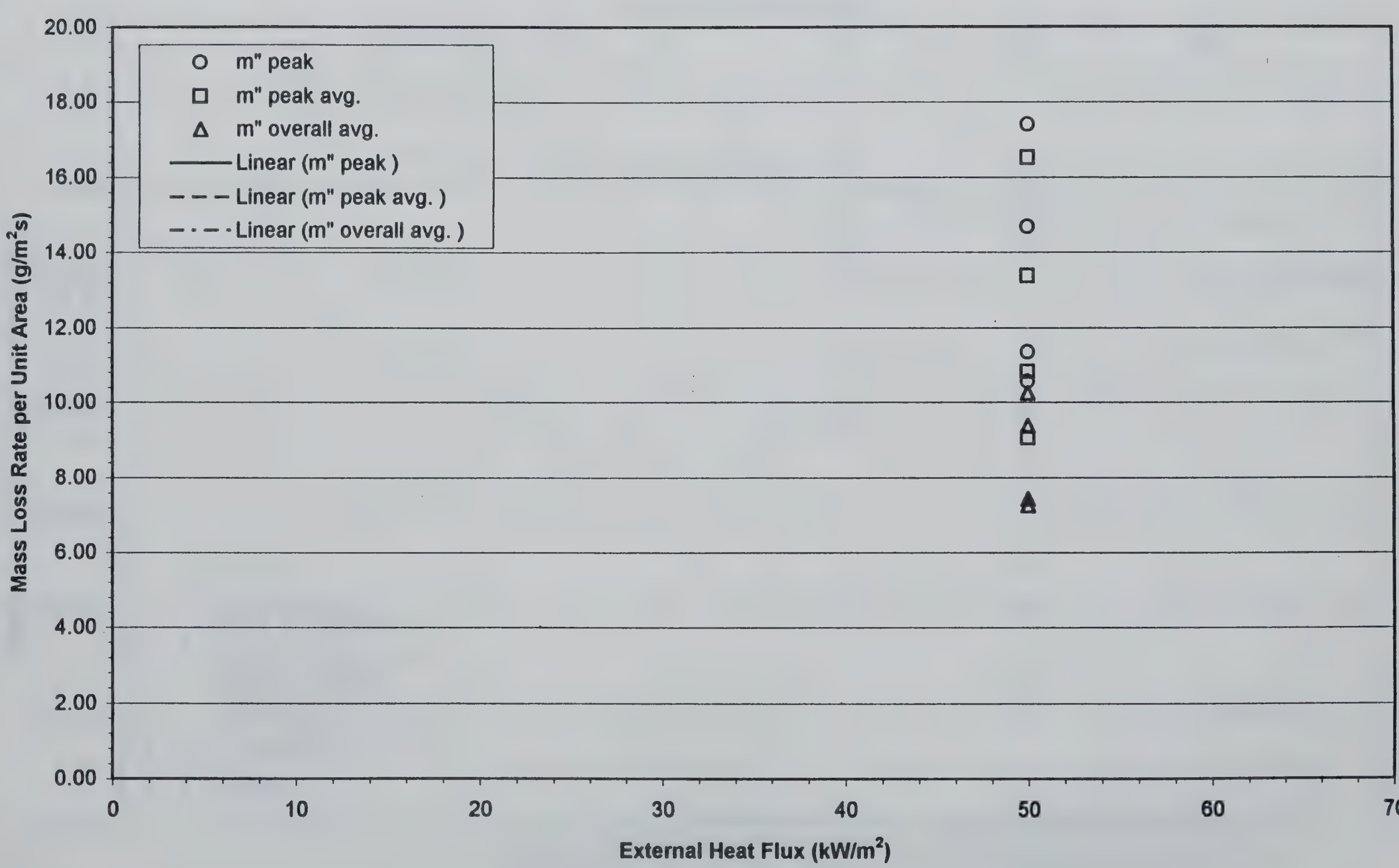
4.02 Paper Faced Gypsum Board: Mass Loss Rate vs. External Heat Flux



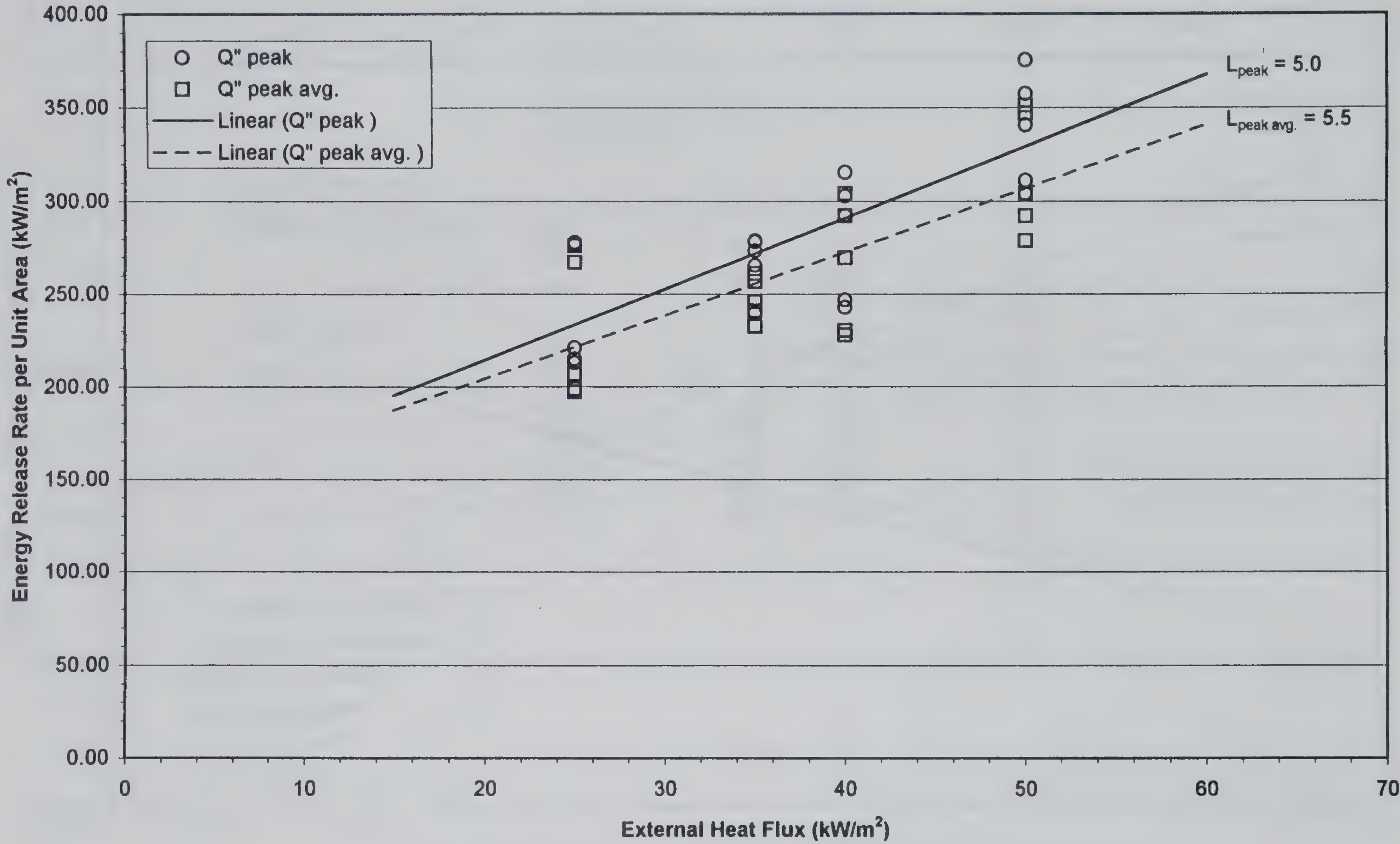
R 4.03 Energy Release Rate vs. External Heat Flux



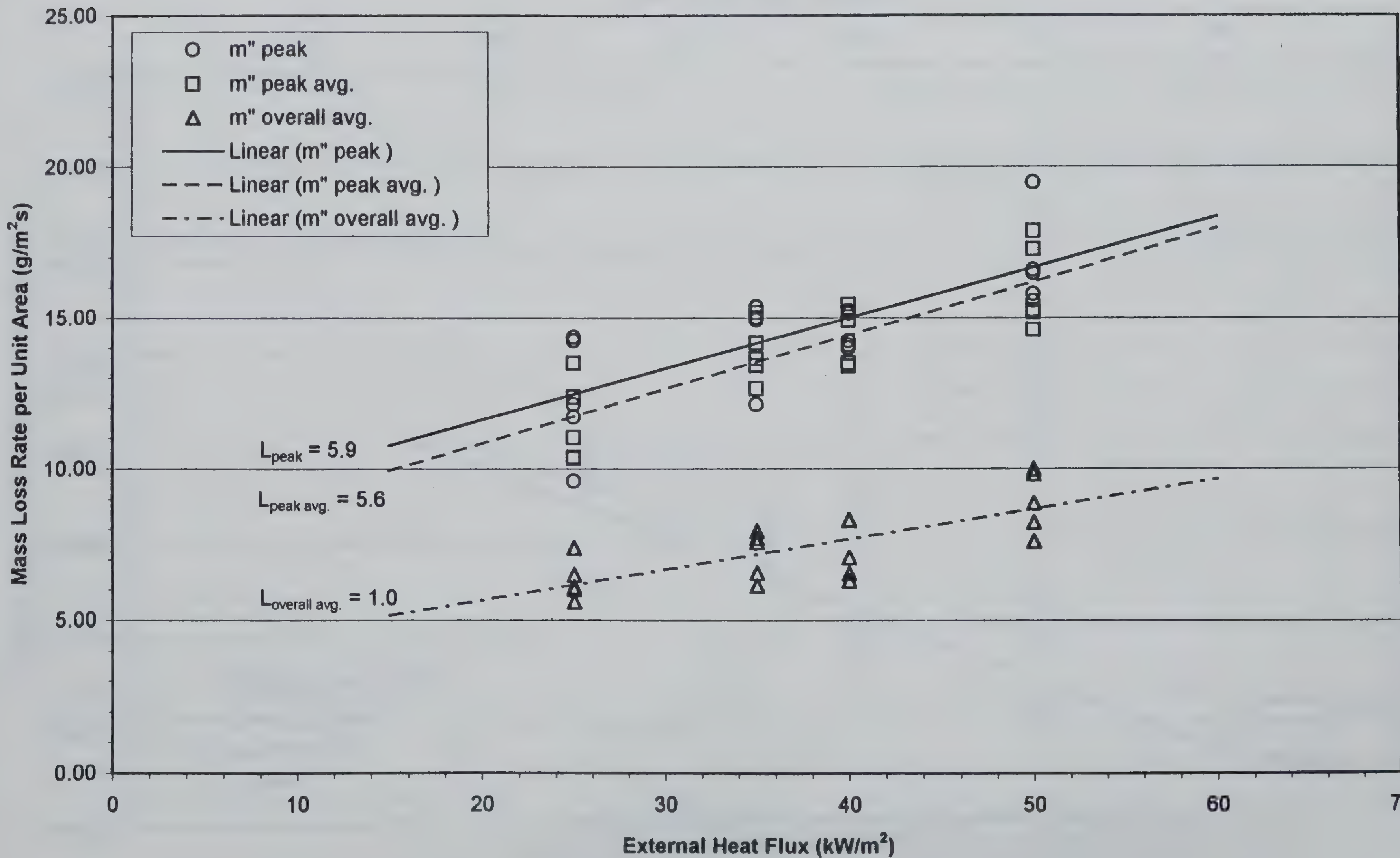
R 4.03 Mass Loss Rate vs. External Heat Flux



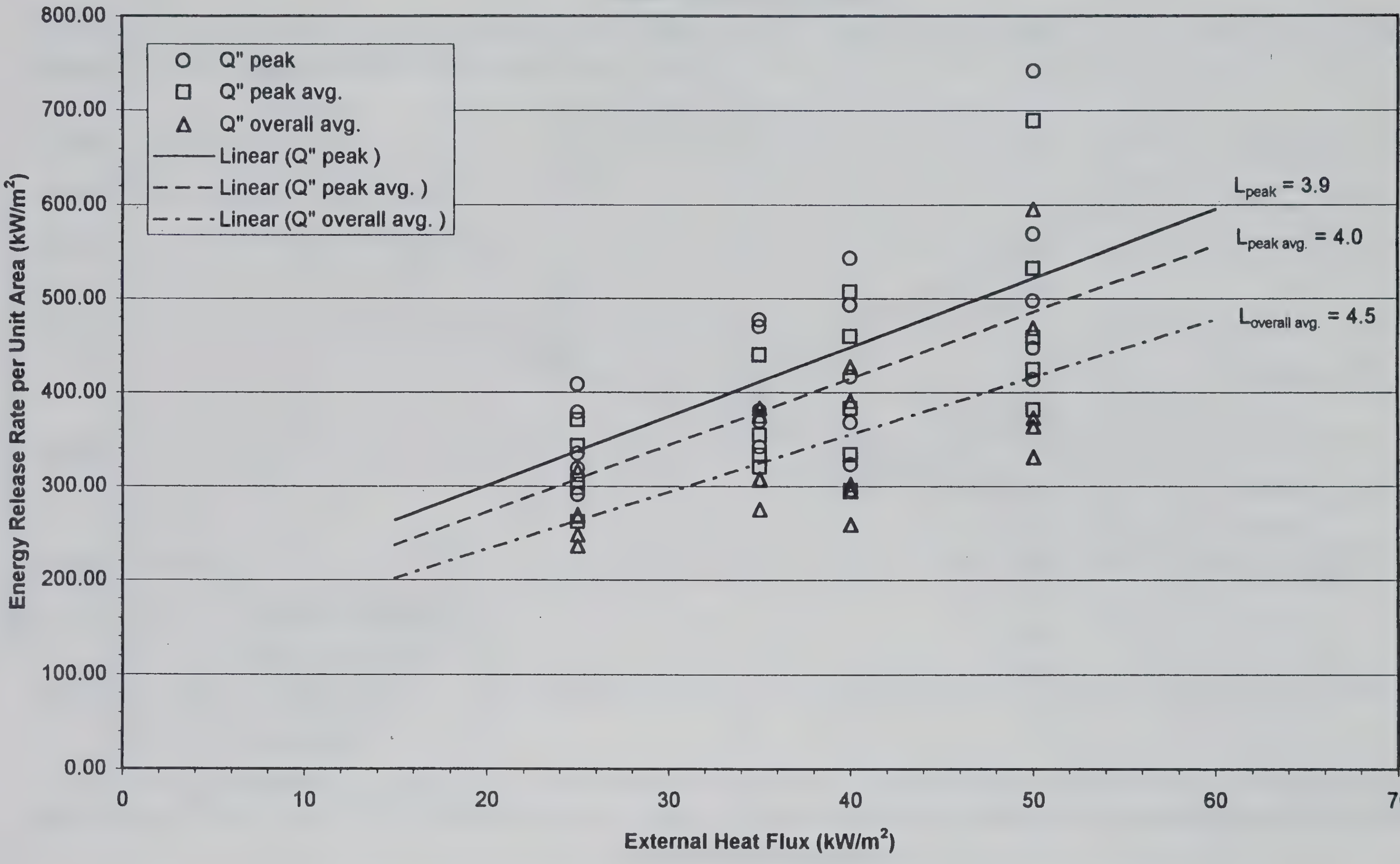
4.04 Polyurethane with Paper Backing: Energy Release Rate vs. External Heat Flux



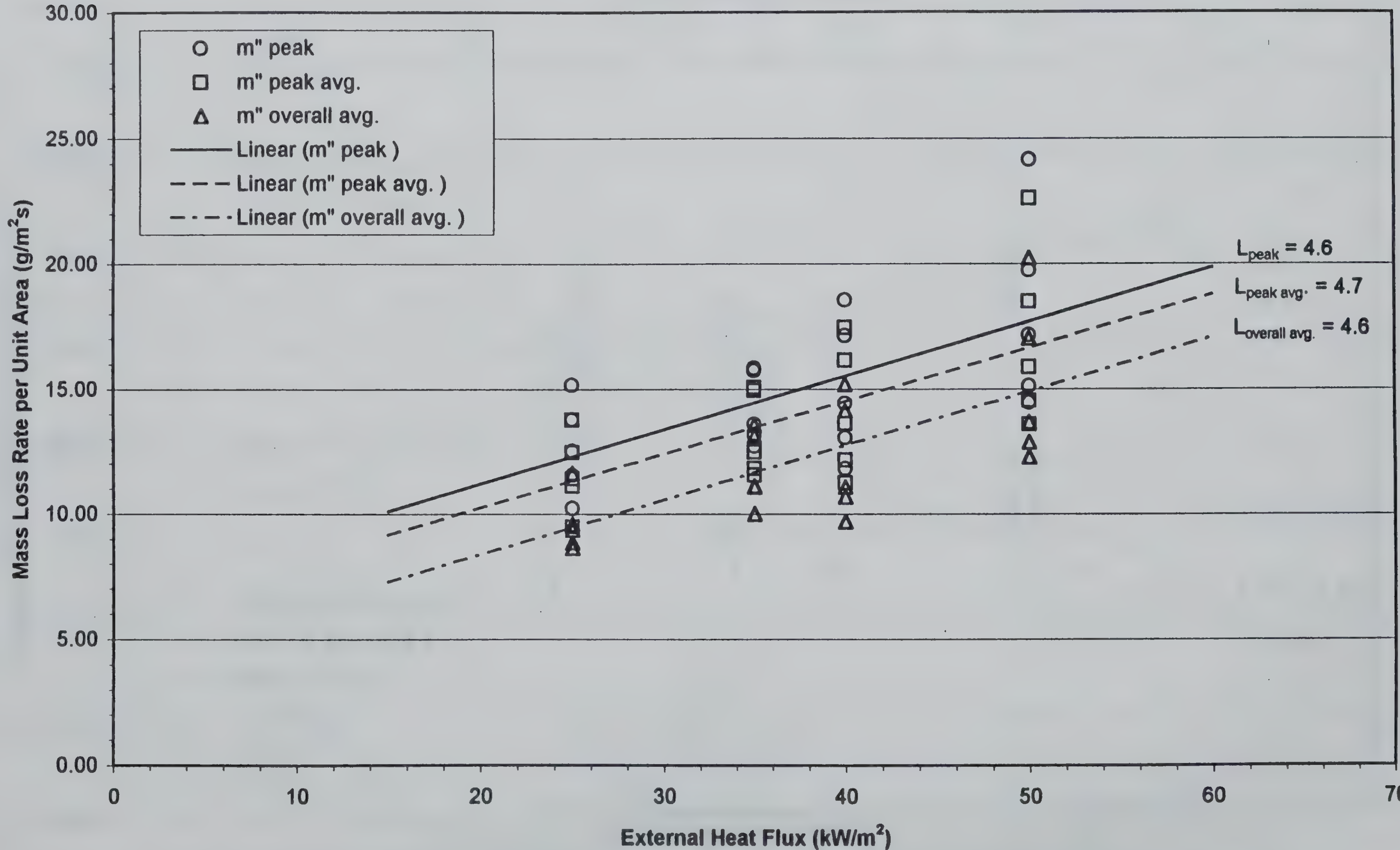
4.04 Polyurethane with Paper Backing: Mass Loss Rate vs. External Heat Flux



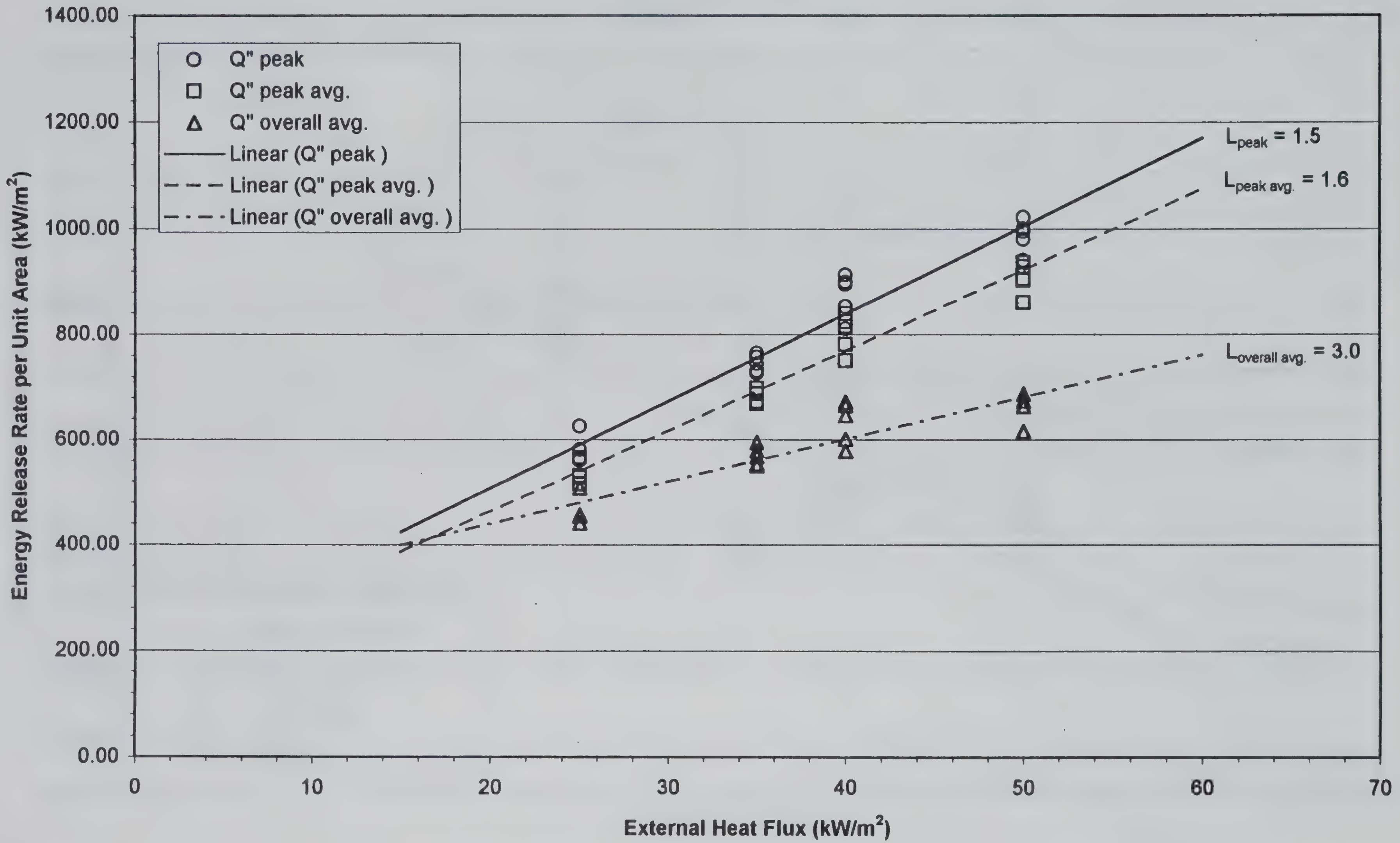
4.05 F.R. Extruded Polystyrene Board (40 mm): Energy Release Rate vs. External Heat Flux



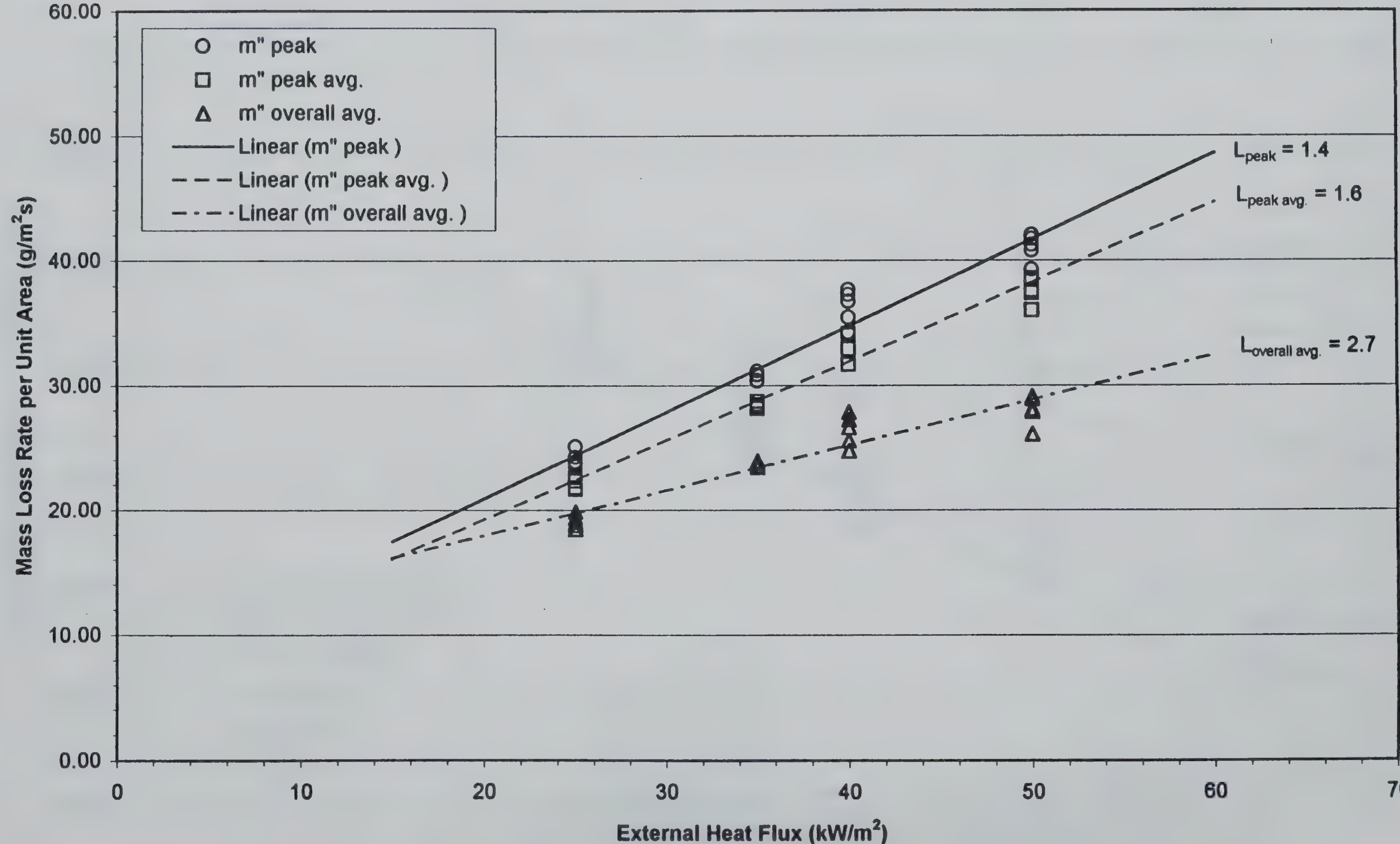
4.05 F.R. Extruded Polystyrene Board (40 mm): Mass Loss Rate vs. External Heat Flux



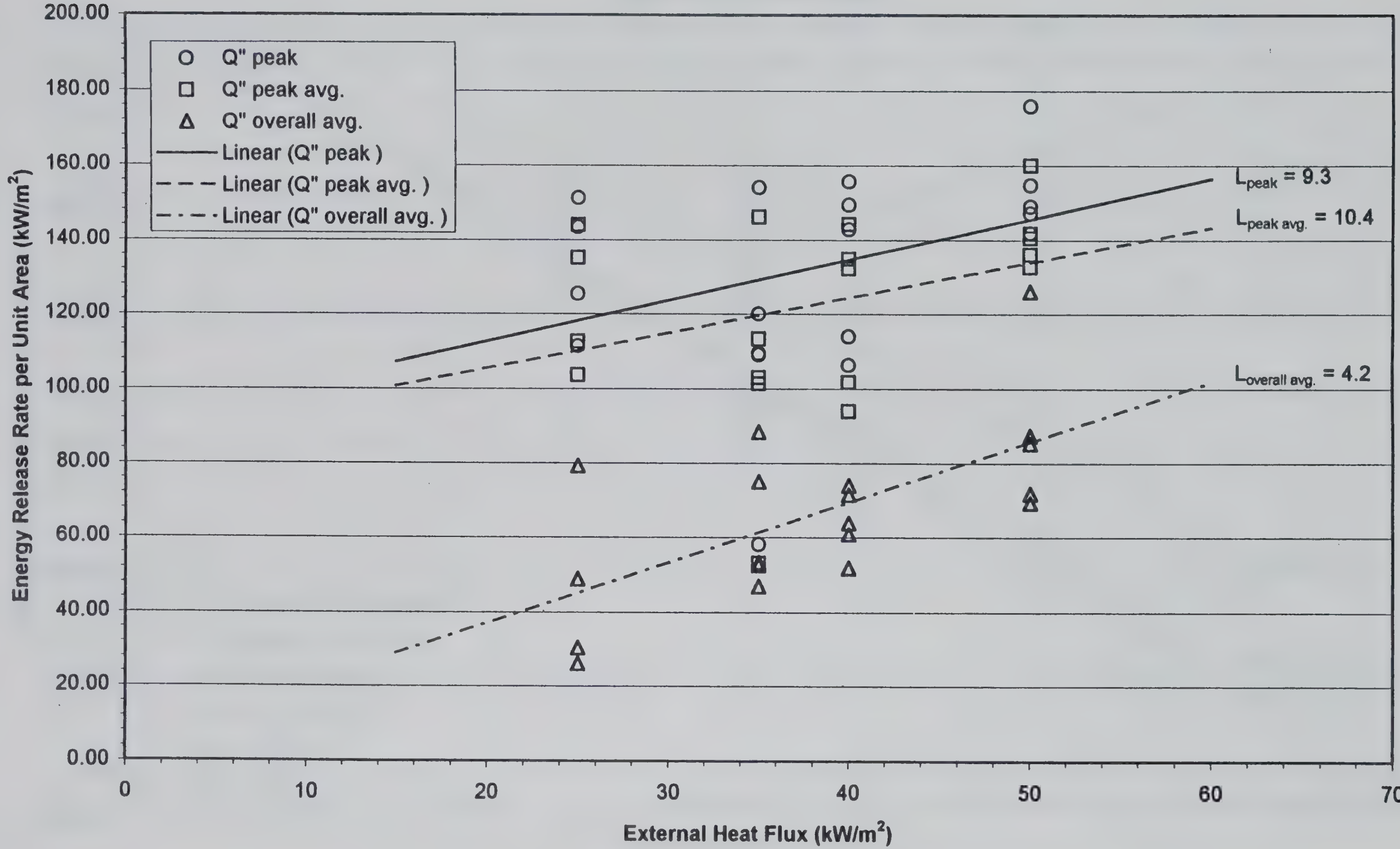
4.06 Acrylic Glazing: Energy Release Rate vs. External Heat Flux



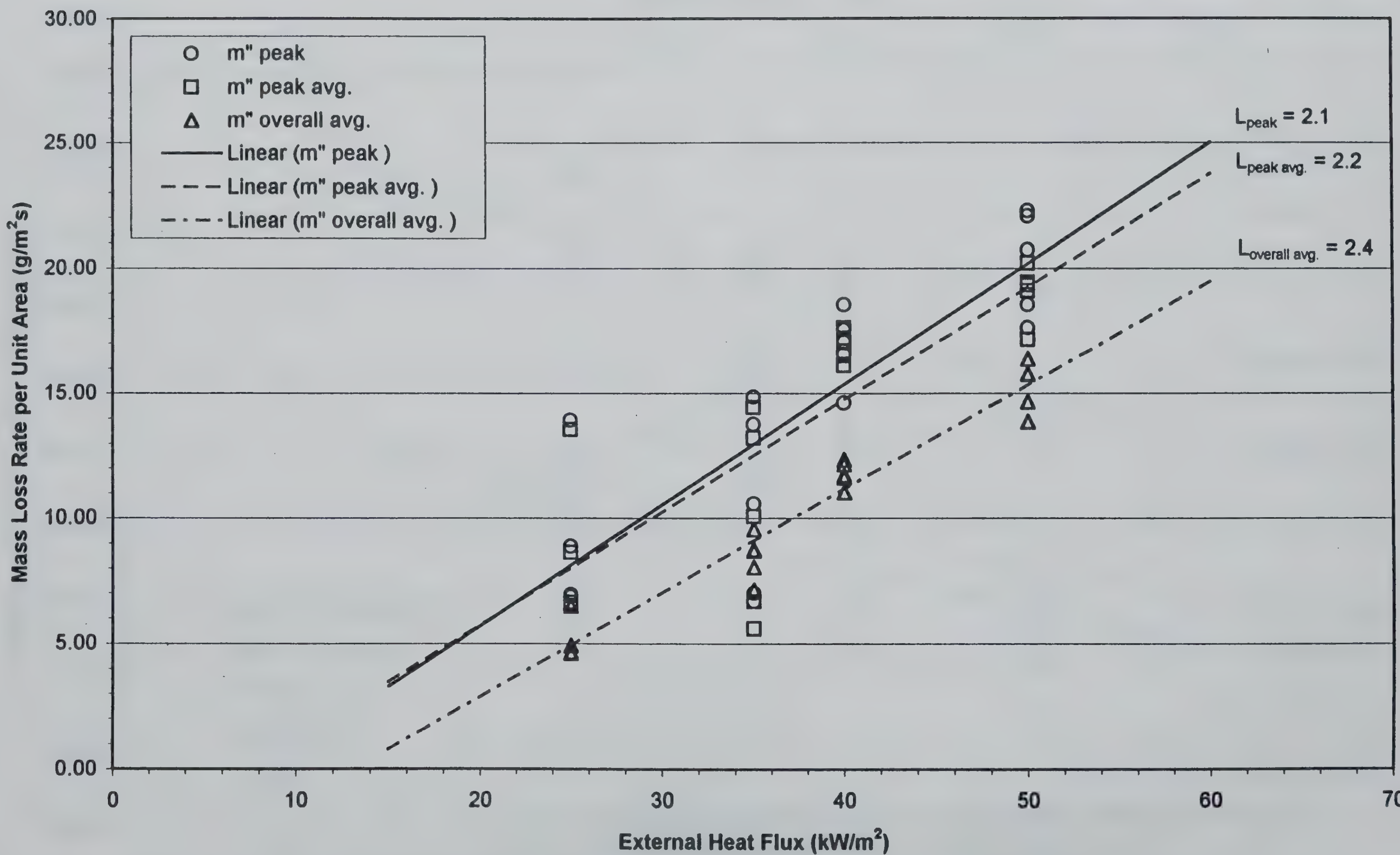
4.06 Acrylic Glazing: Mass Loss Rate vs. Externalt Heat Flux



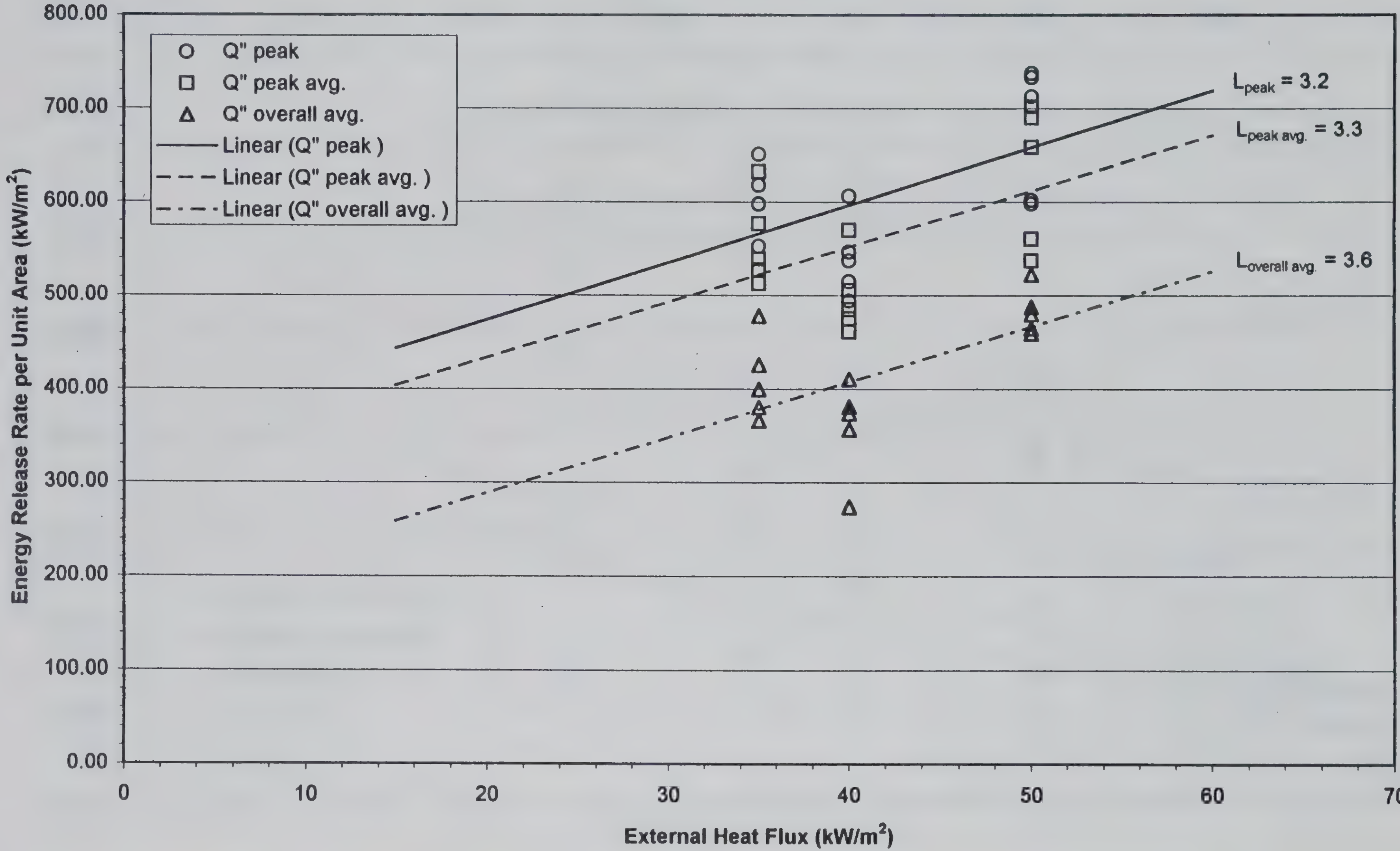
4.07 Energy Release Rate vs. External Heat Flux



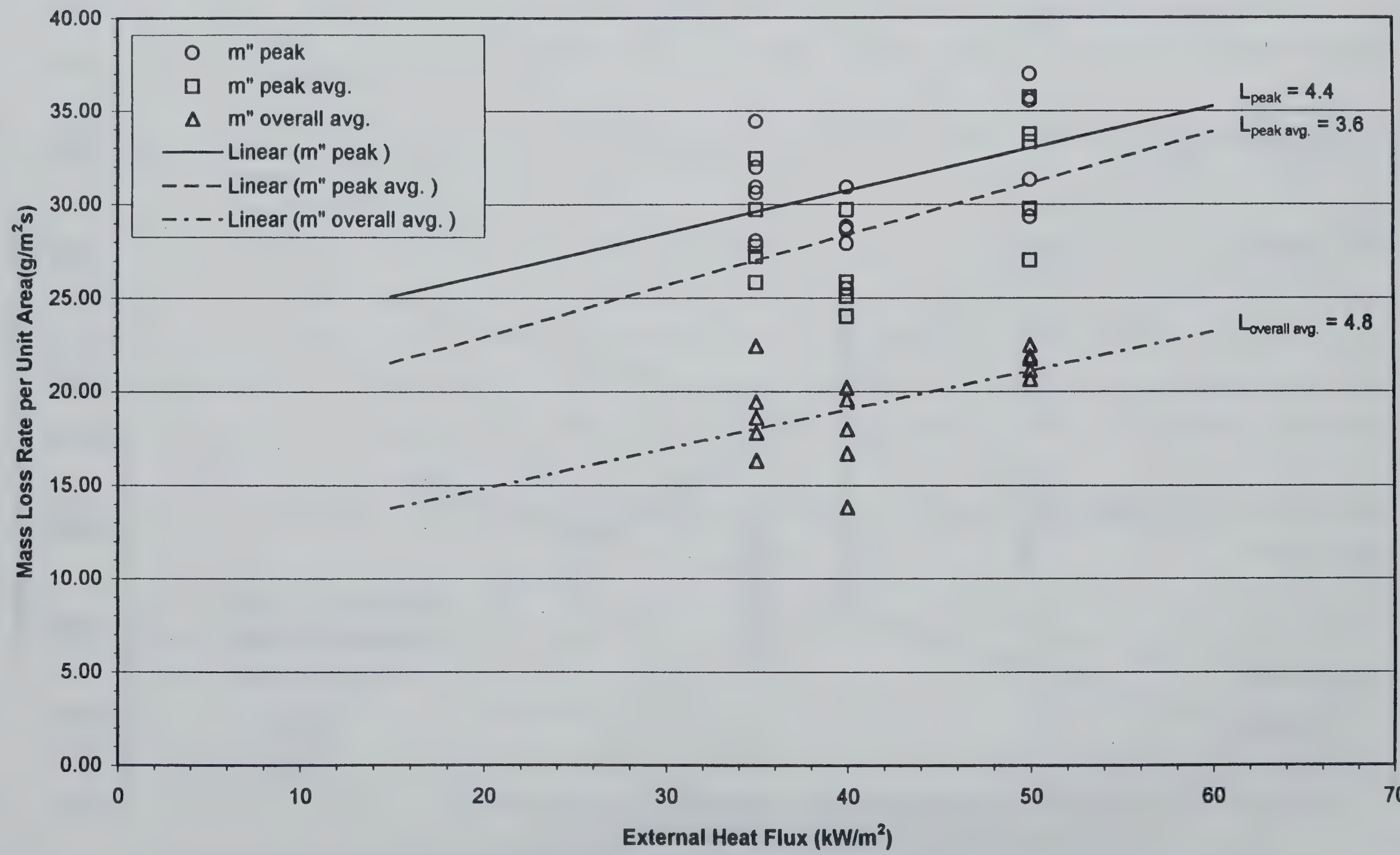
4.07 Mass Loss vs. External Heat Flux



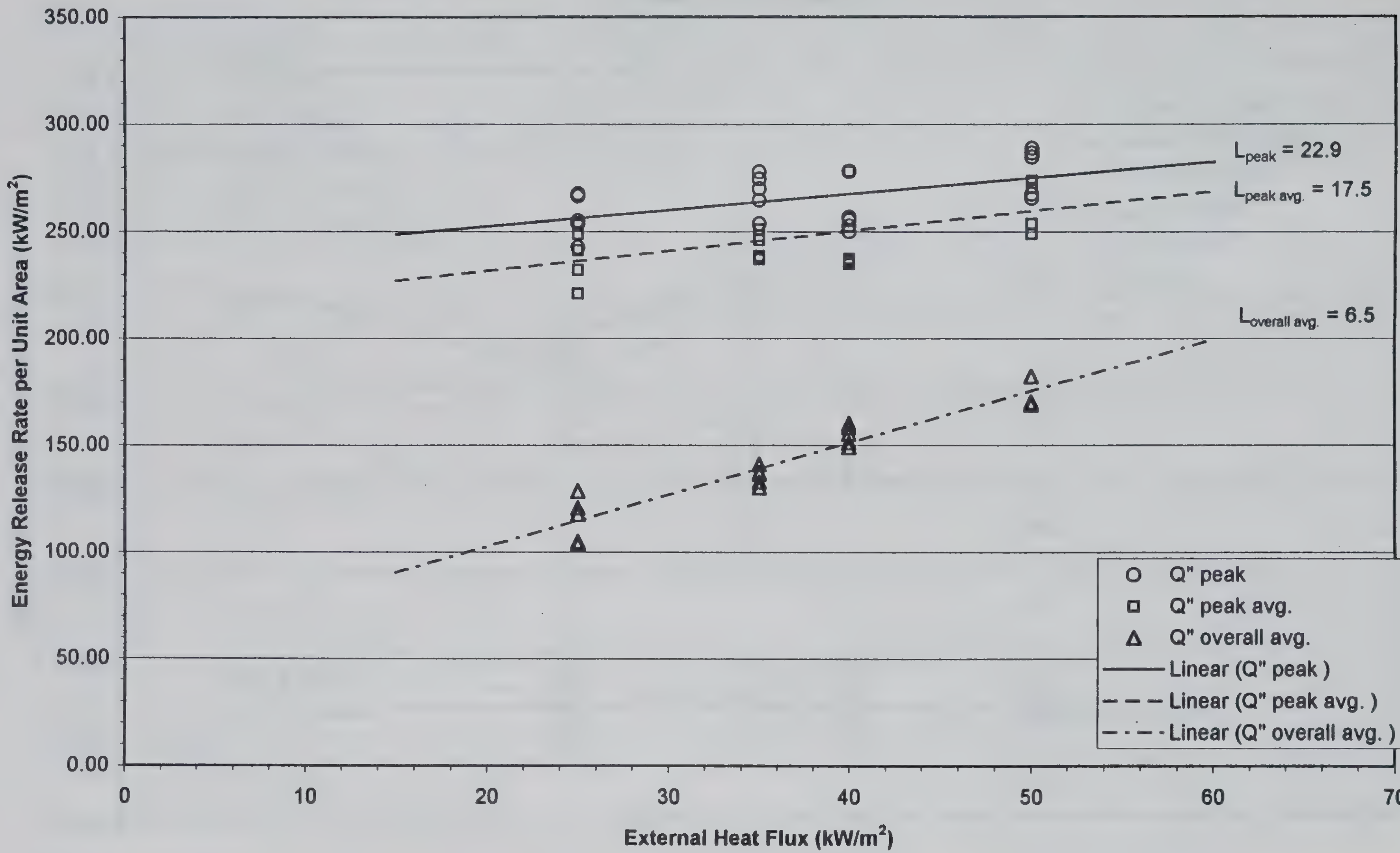
4.08 3-Layered F.R. Polycarbonate Panel: Energy Release Rate vs. External Heat Flux

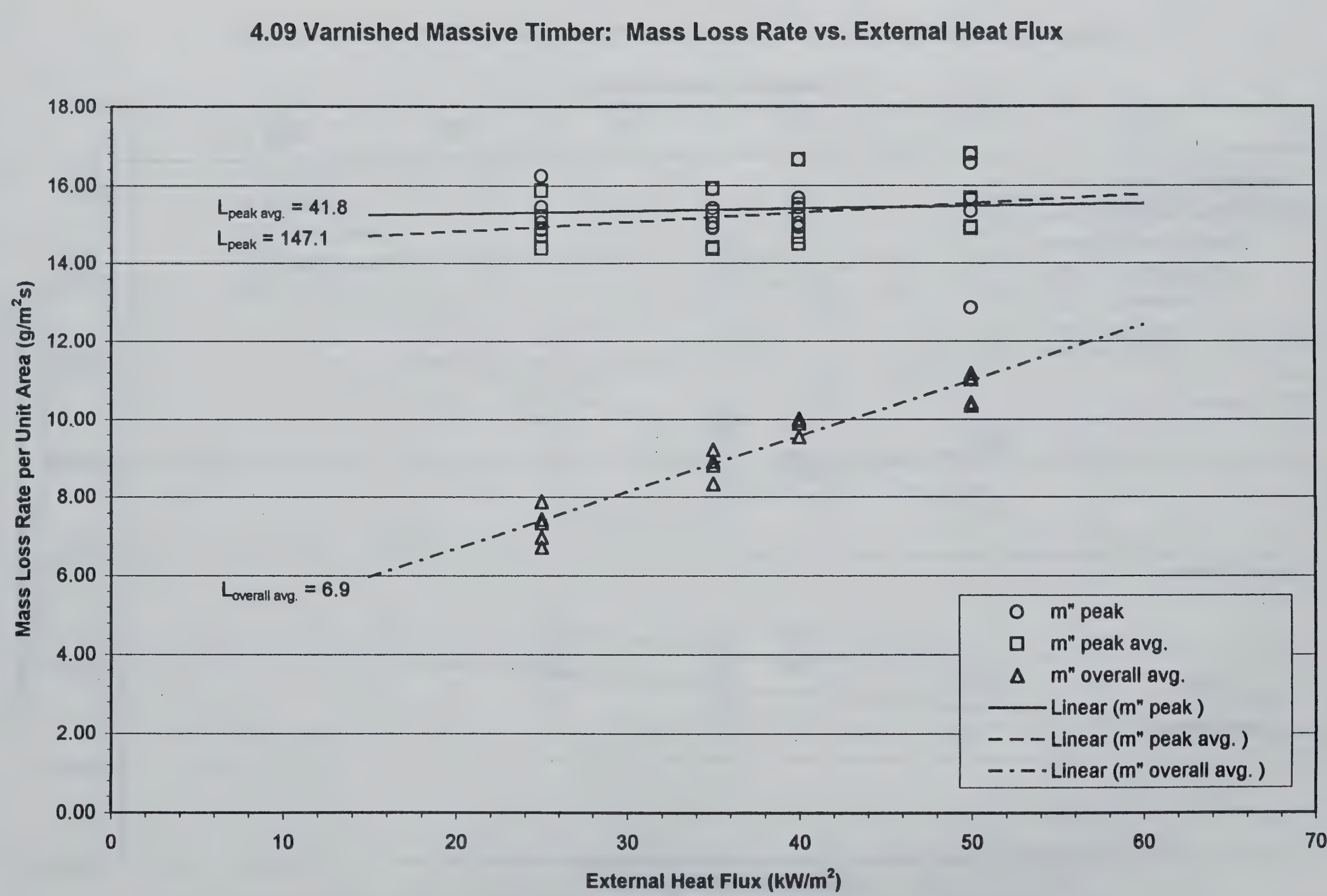


4.08 3-Layered F.R. Polycarbonate Panel: Mass Loss Rate vs. External Heat Flux



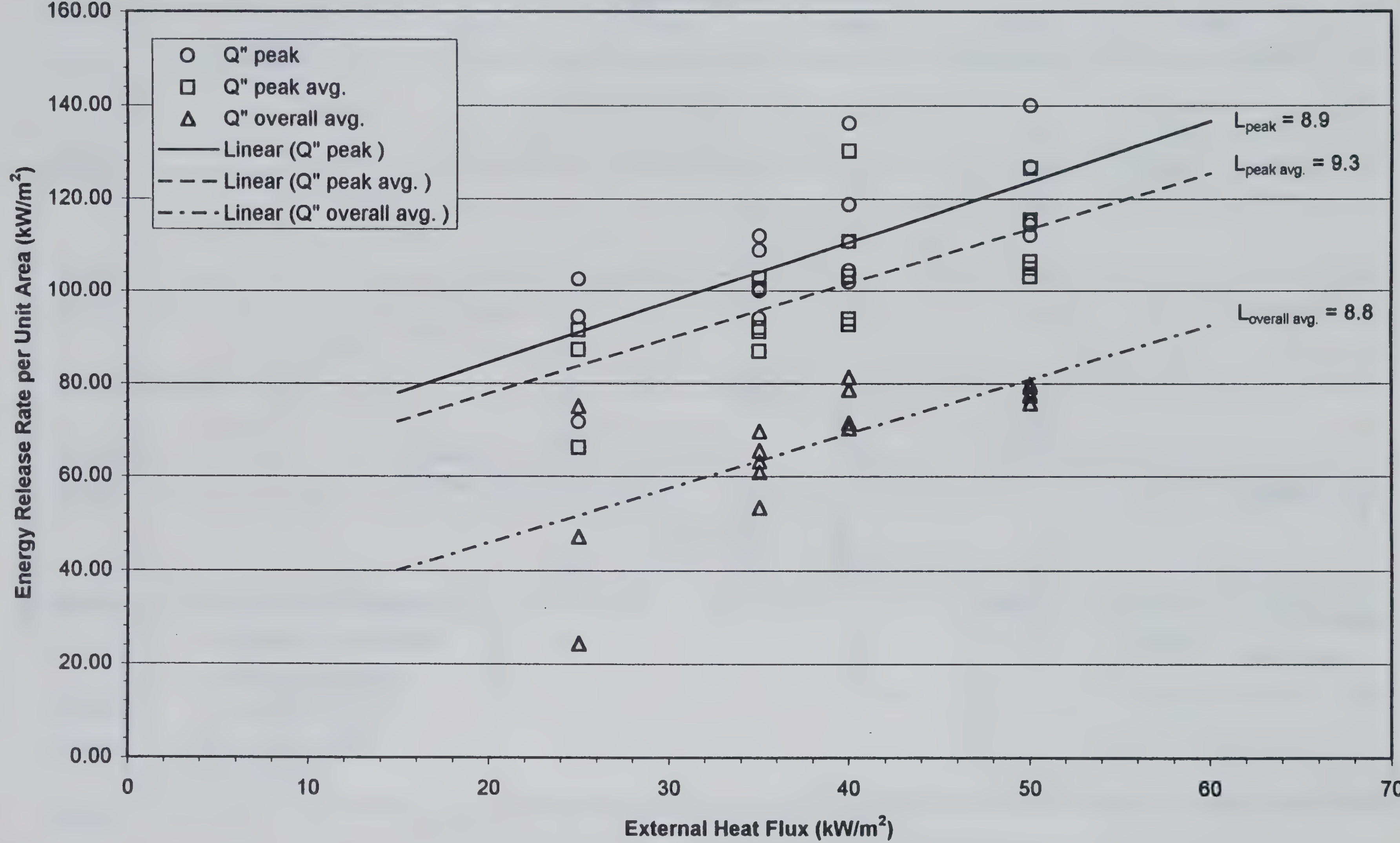
4.09 Varnished Massive Timber: Energy Release Rate vs. External Heat Flux



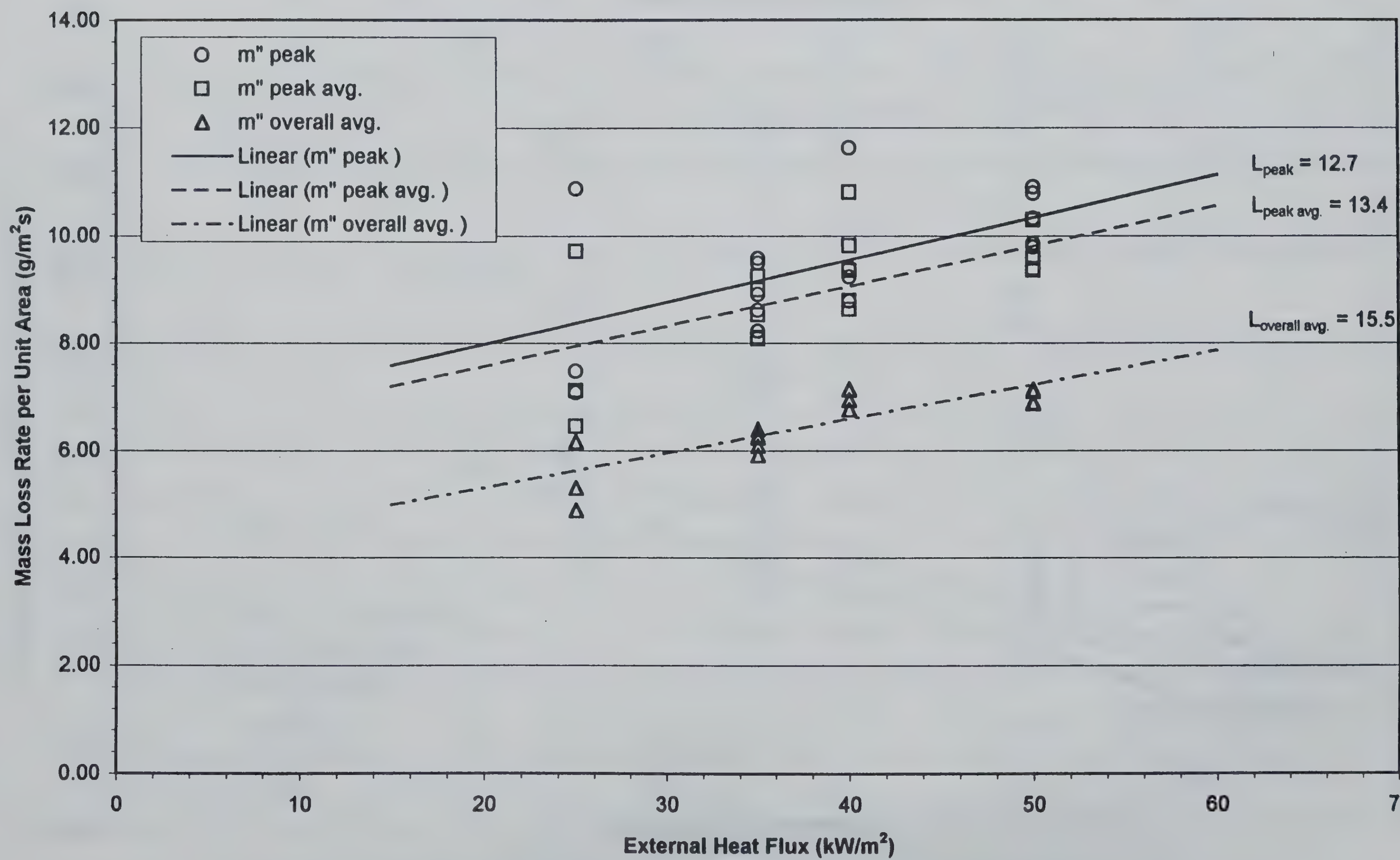


4.09 Varnished Massive Timber: Mass Loss Rate vs. External Heat Flux
Mass Loss Rate per Unit Area (g/m²s)
External Heat Flux (kW/m²)
L peak avg. = 41.8
L peak = 147.1
L overall avg. = 6.9
m" peak
m" peak avg.
m" overall avg.
Linear (m" peak)
Linear (m" peak avg.)
Linear (m" overall avg.)
18.00
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
0
10
20
30
40
50
60
70

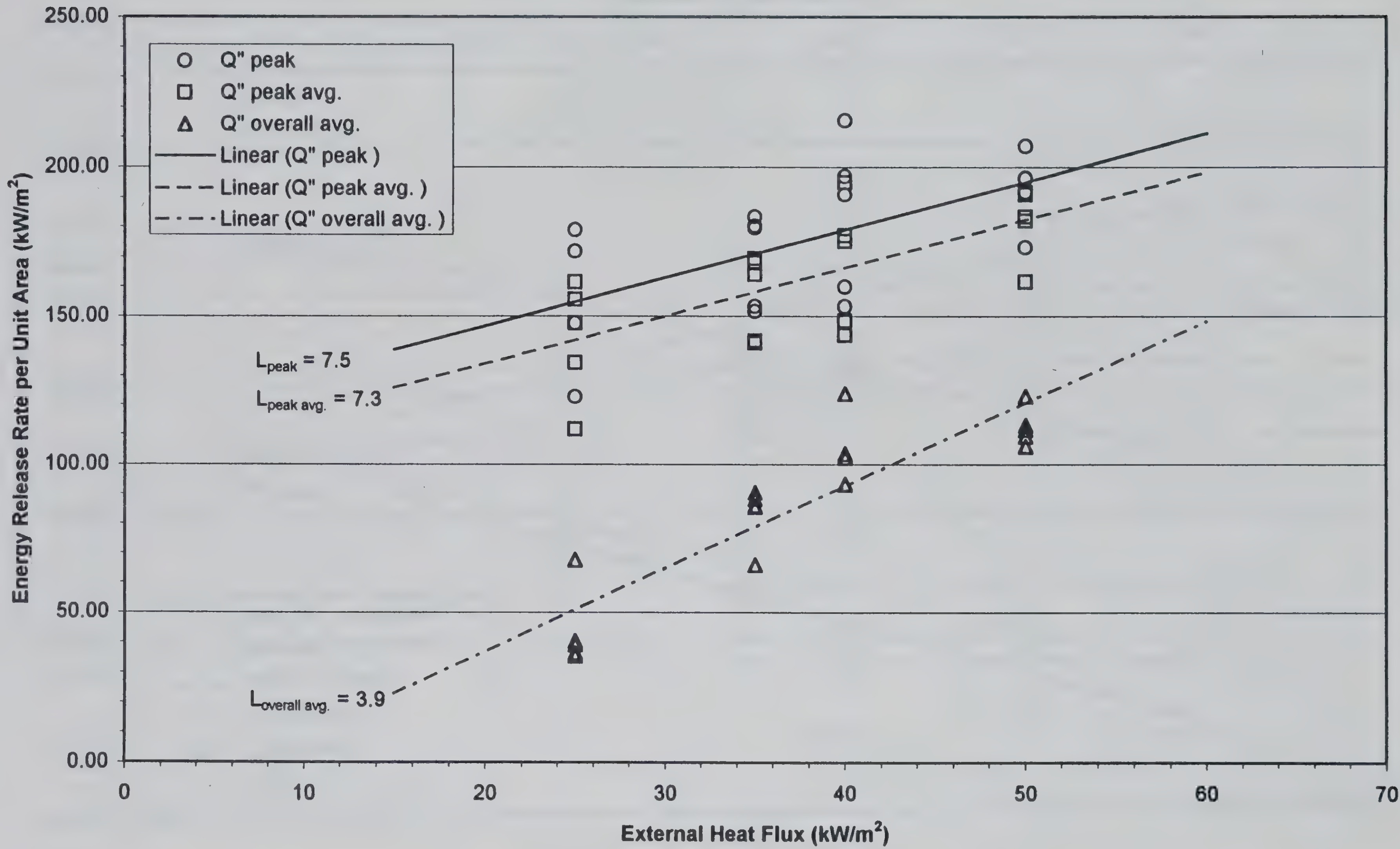
4.10 F.R. Plywood: Energy Release Rate vs. External Heat Flux



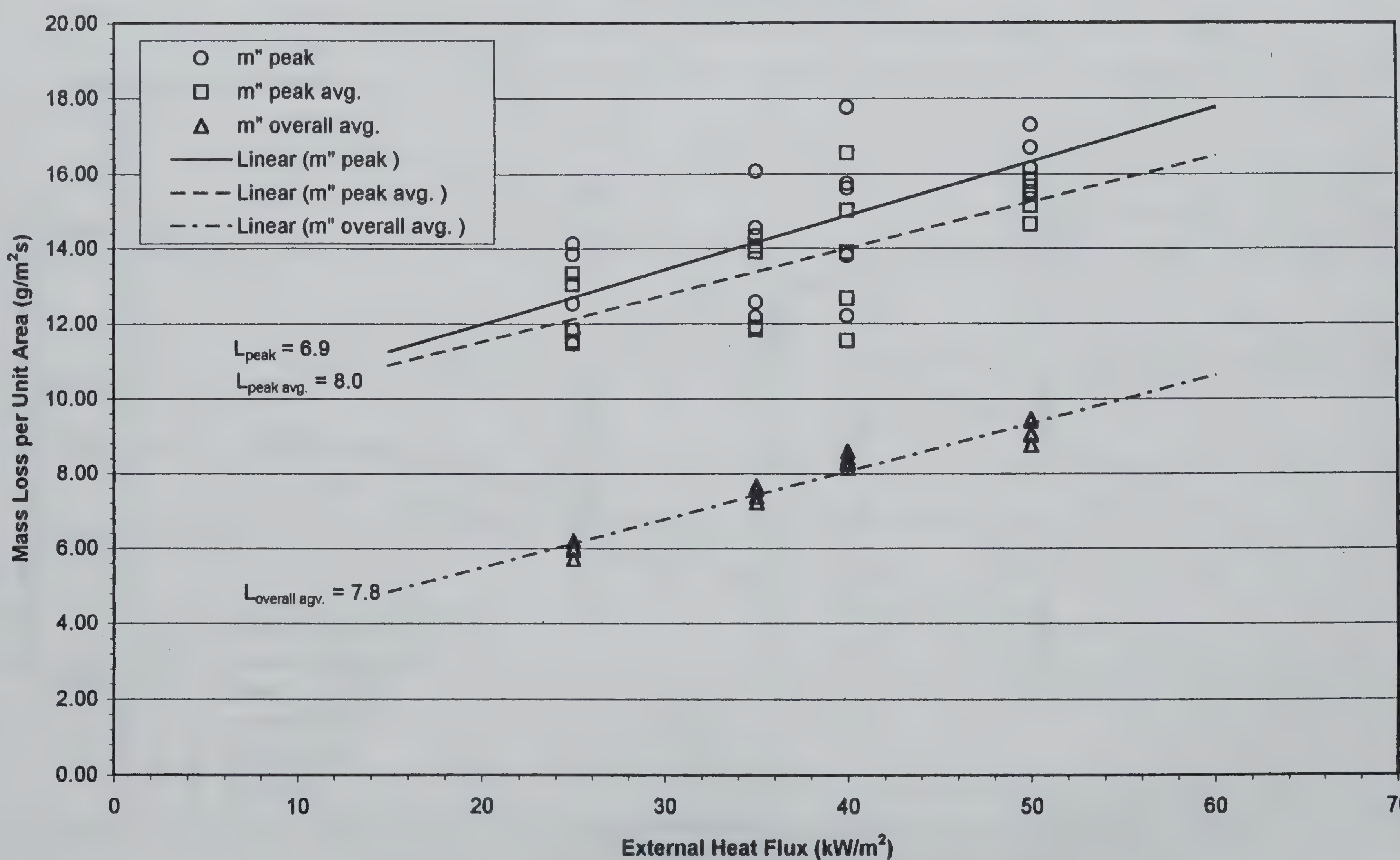
4.10 F.R. Plywood: Mass Loss Rate vs. External Heat Flux



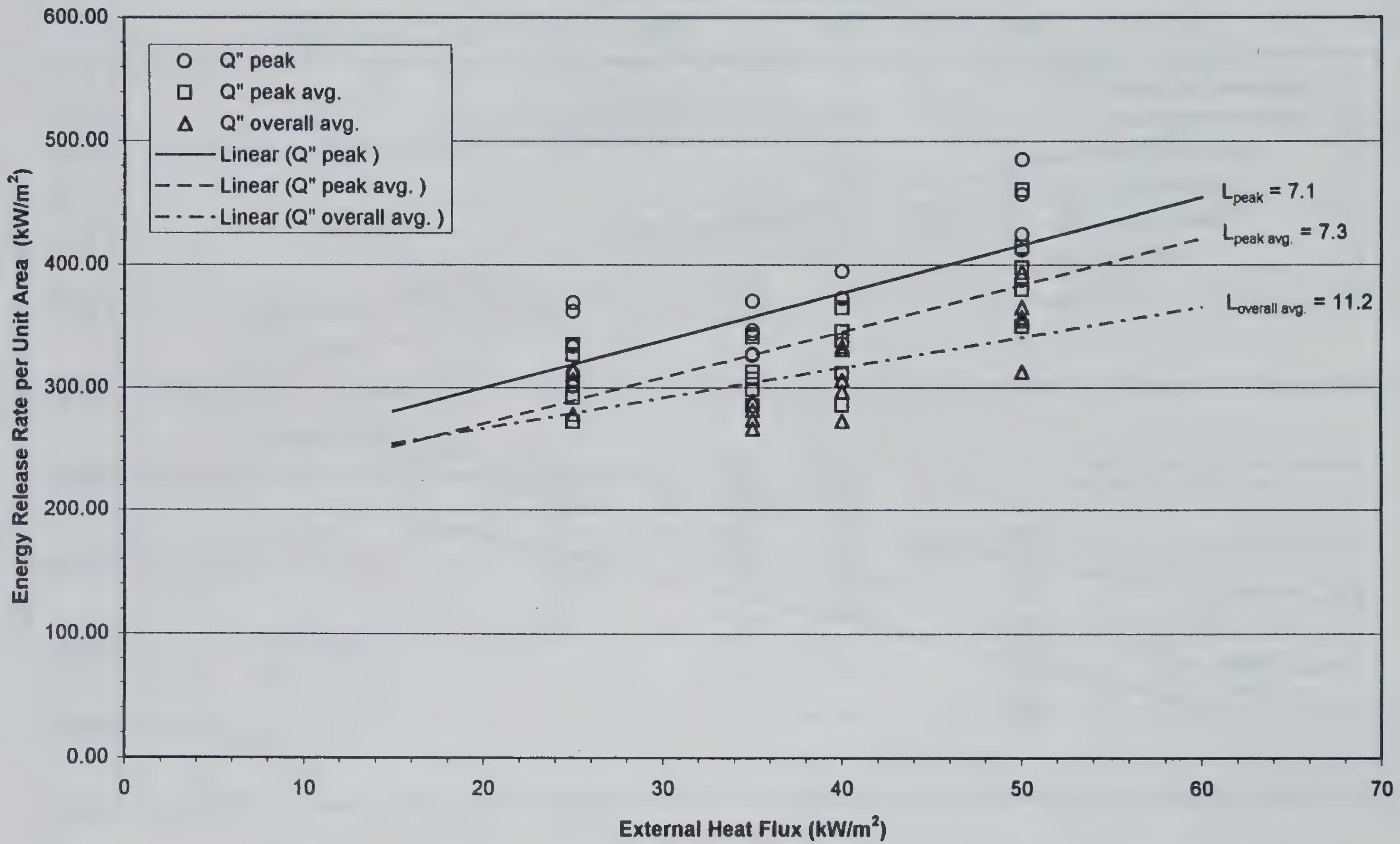
4.11 Normal Plywood: Energy Release Rate vs. External Heat Flux



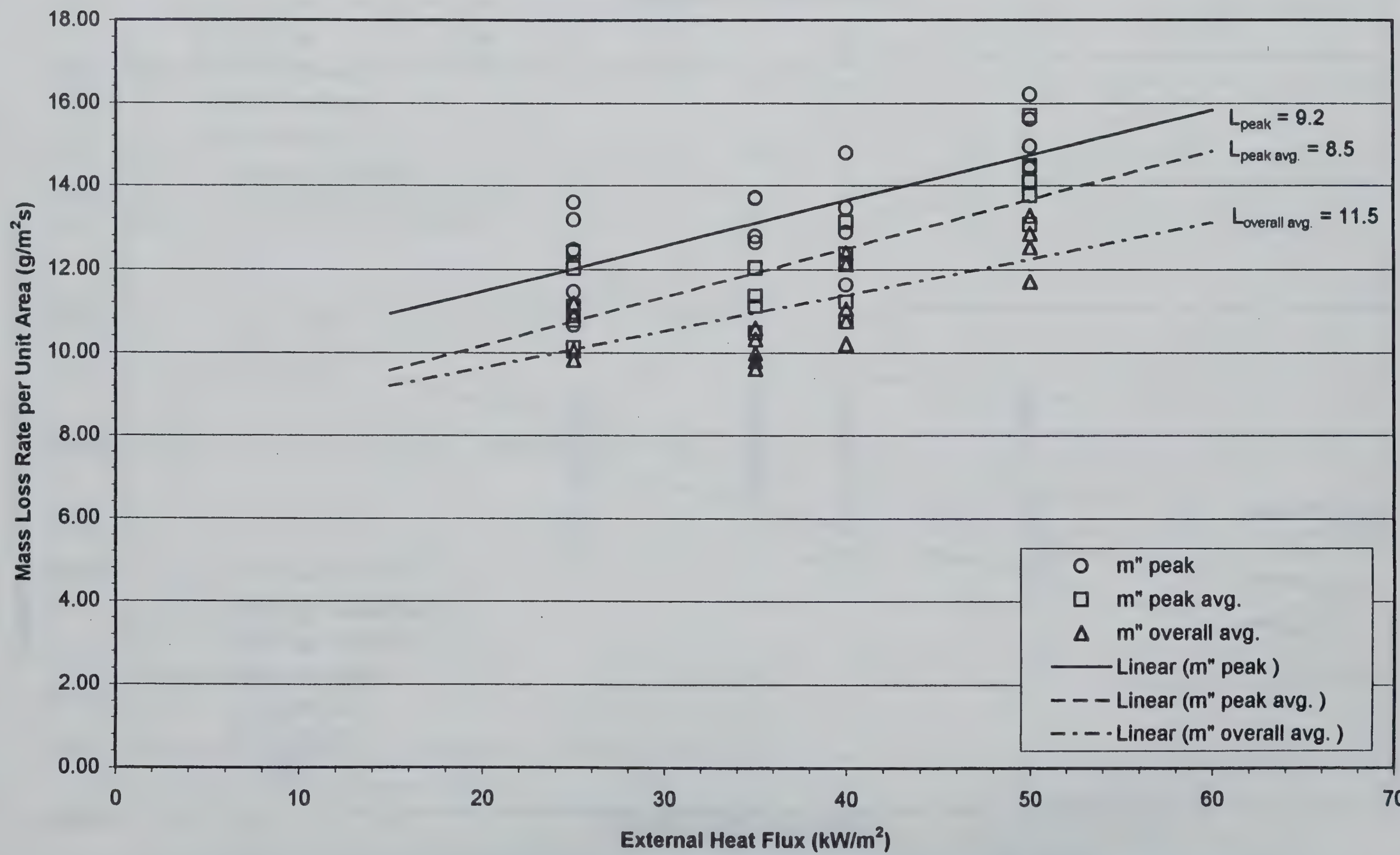
4.11 Normal Plywood: Mass Loss Rate vs. External Heat Flux



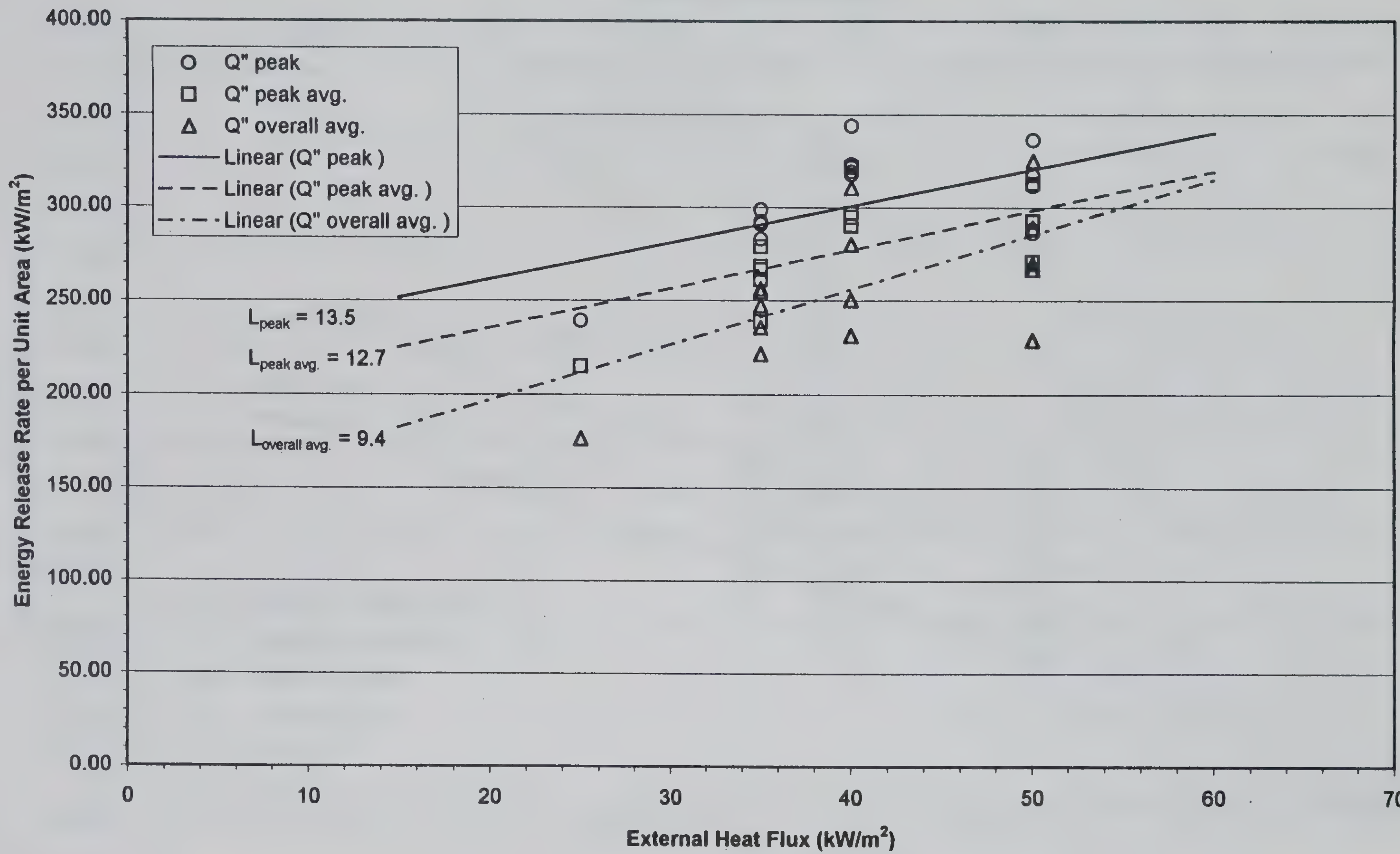
4.20 F.R. Expanded Polystyrene Board (40 mm): Energy Release Rate vs. External Heat Flux



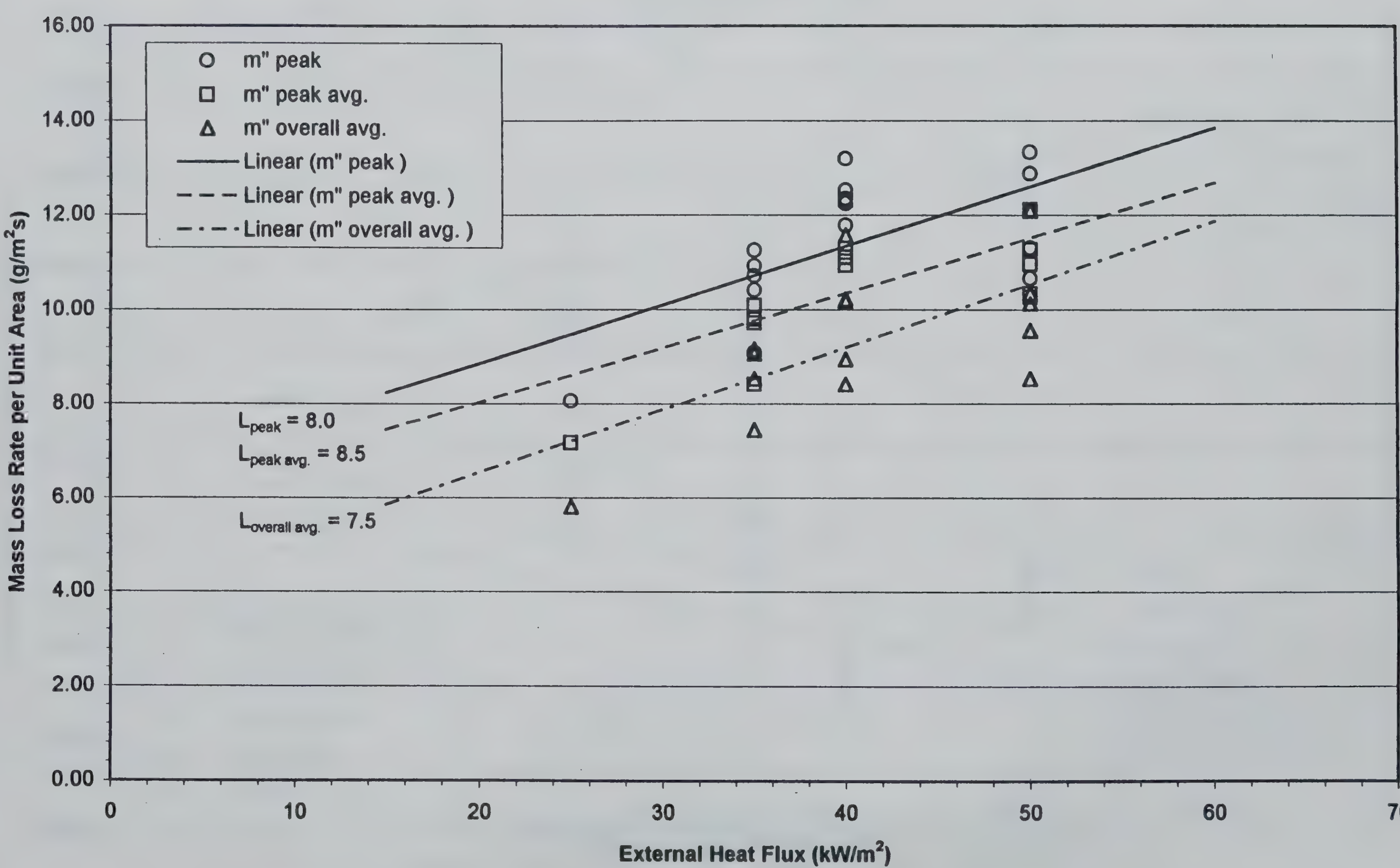
4.20 F.R. Expanded Polystyrene Board (40 mm): Mass Loss Rate vs. External Heat Flux



4.21 F.R. Expanded Polystyrene Board (80 mm): Energy Release Rate vs. External Heat Flux

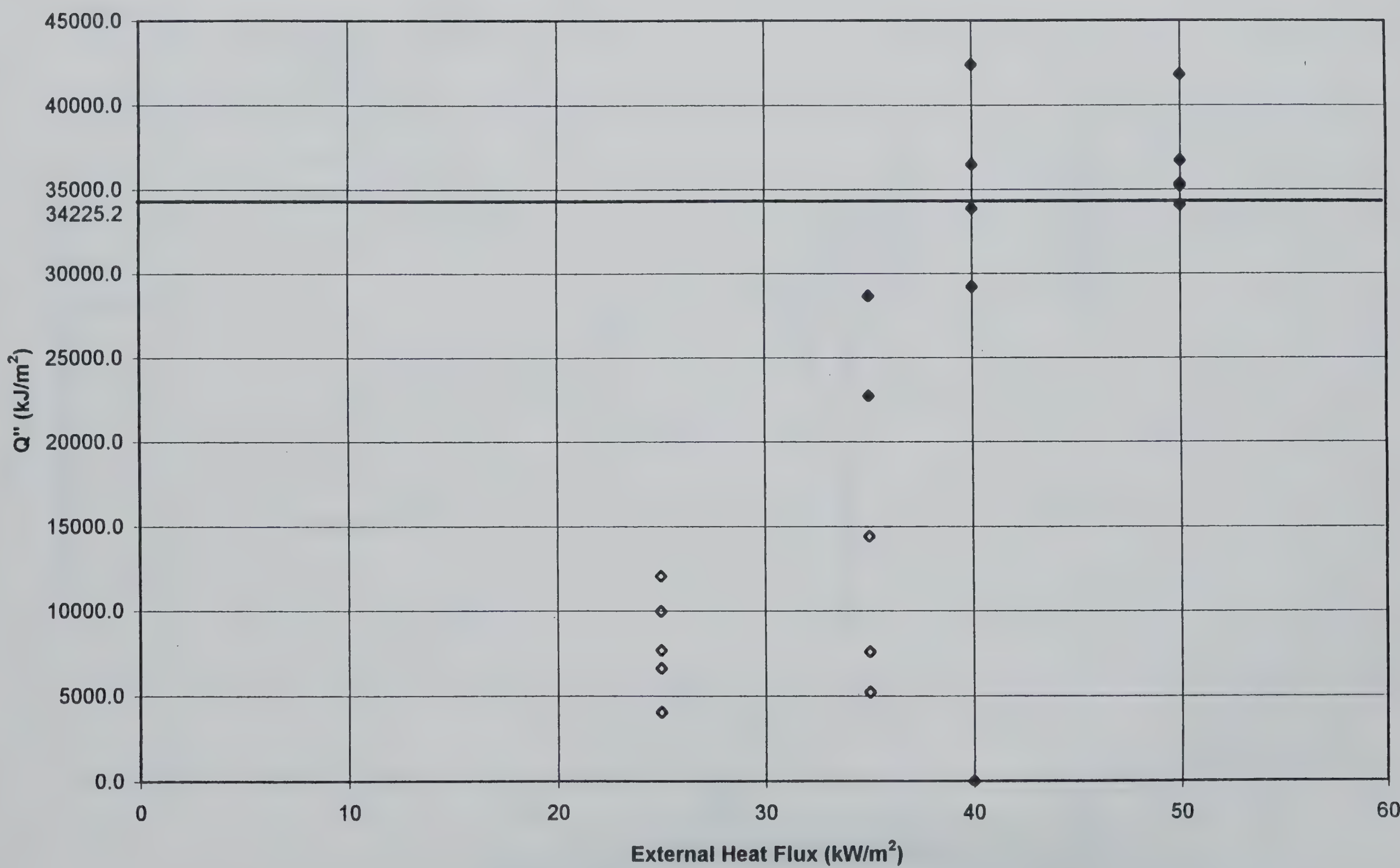


4.21 F.R. Expanded Polystyrene Board (80 mm): Mass Loss Rate vs. External Heat Flux

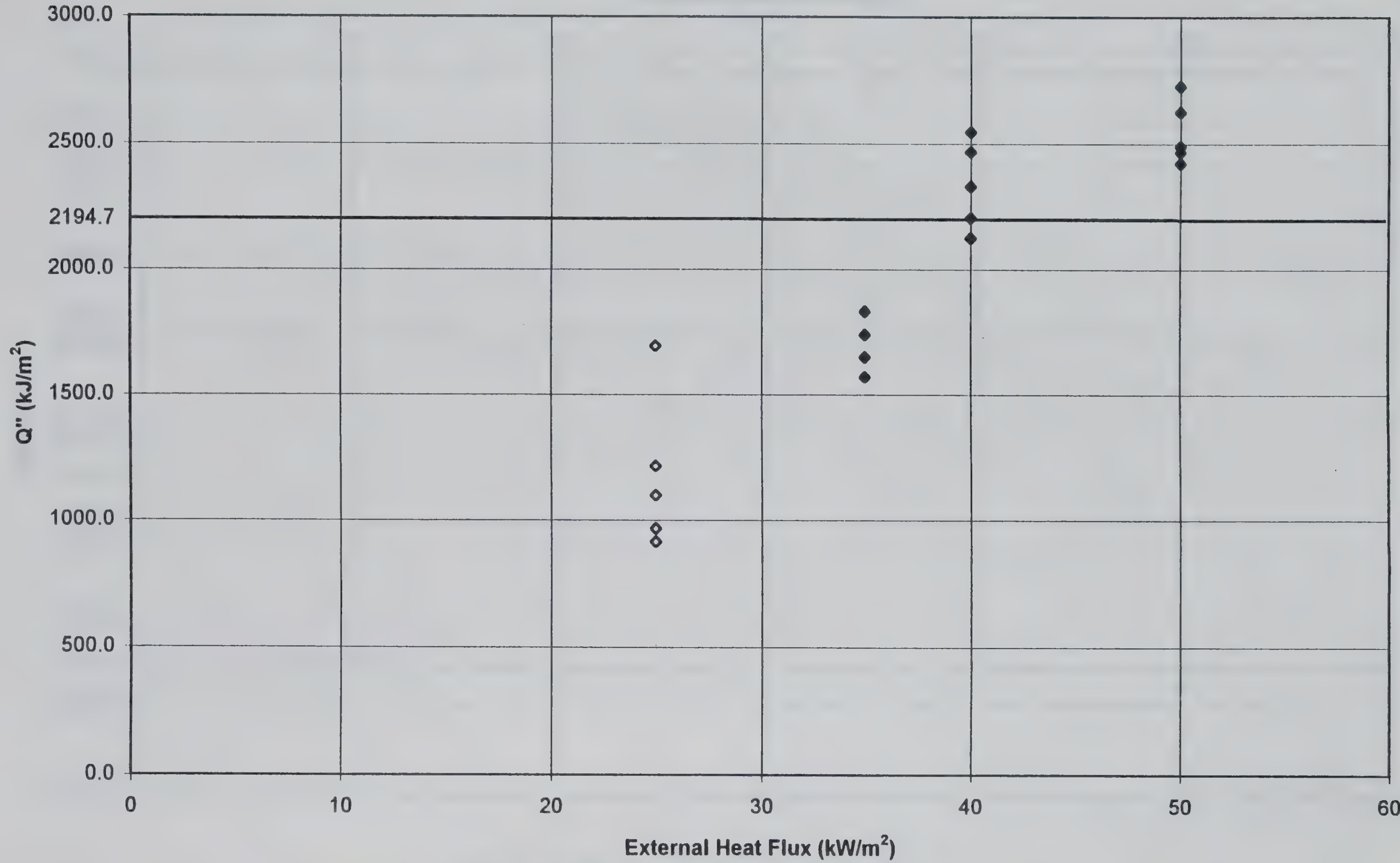


A.6 – Total Energy Per Unit Area Data

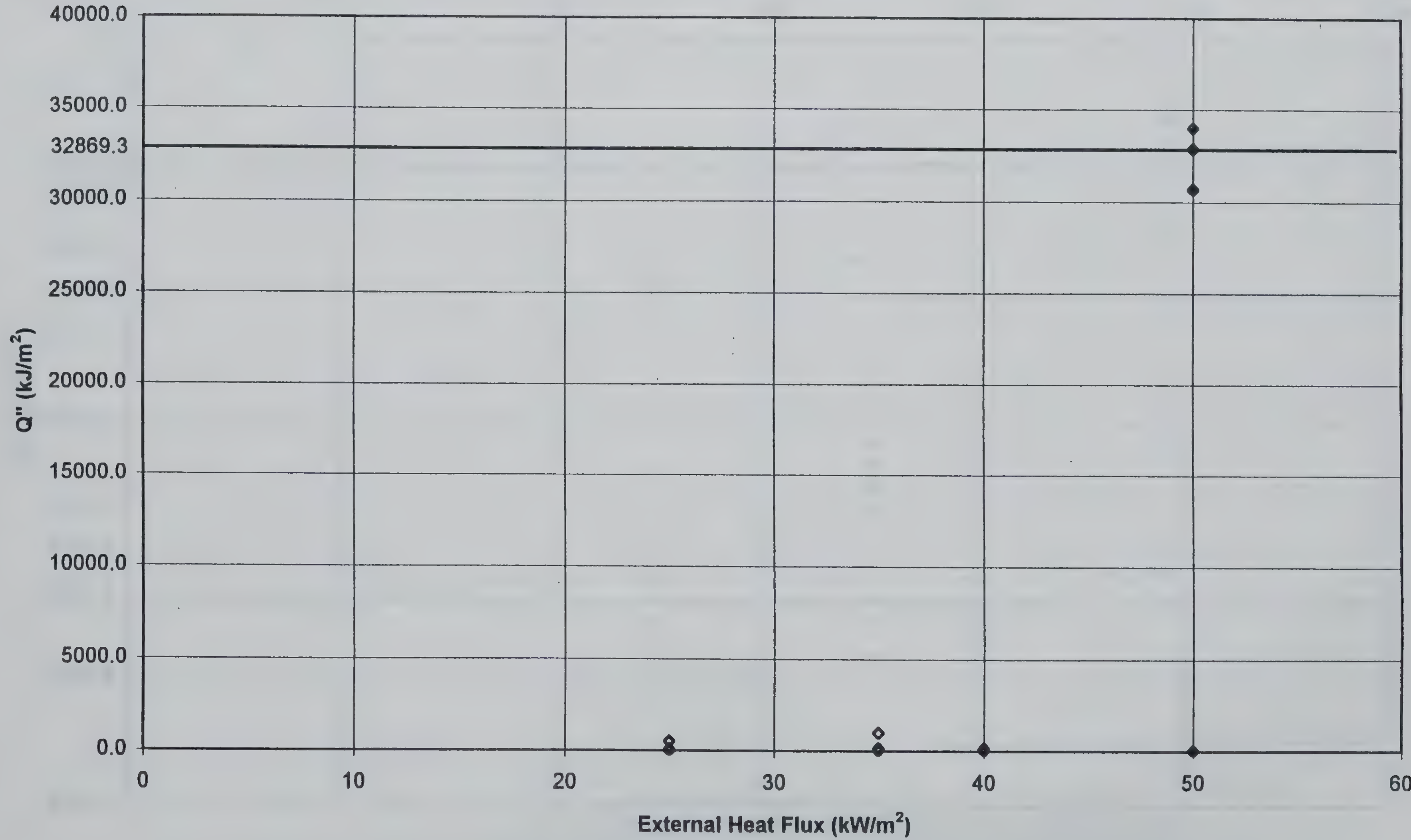
R 4.01 F.R. Chipboard: Total Heat Evolved vs. External Heat Flux



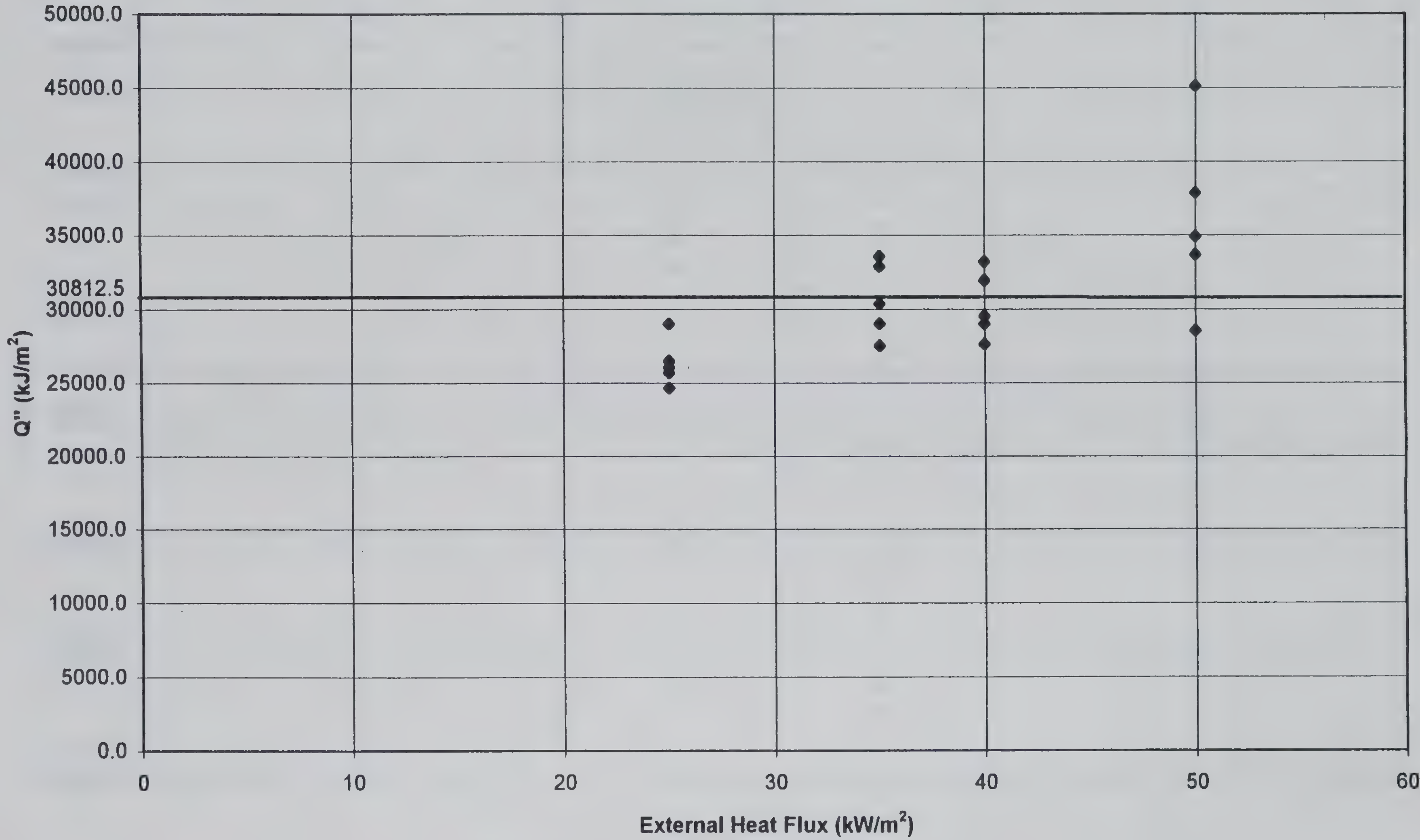
R 4.02 Paper Faced Gypsum Board: Total Heat Evolved vs. External Heat Flux



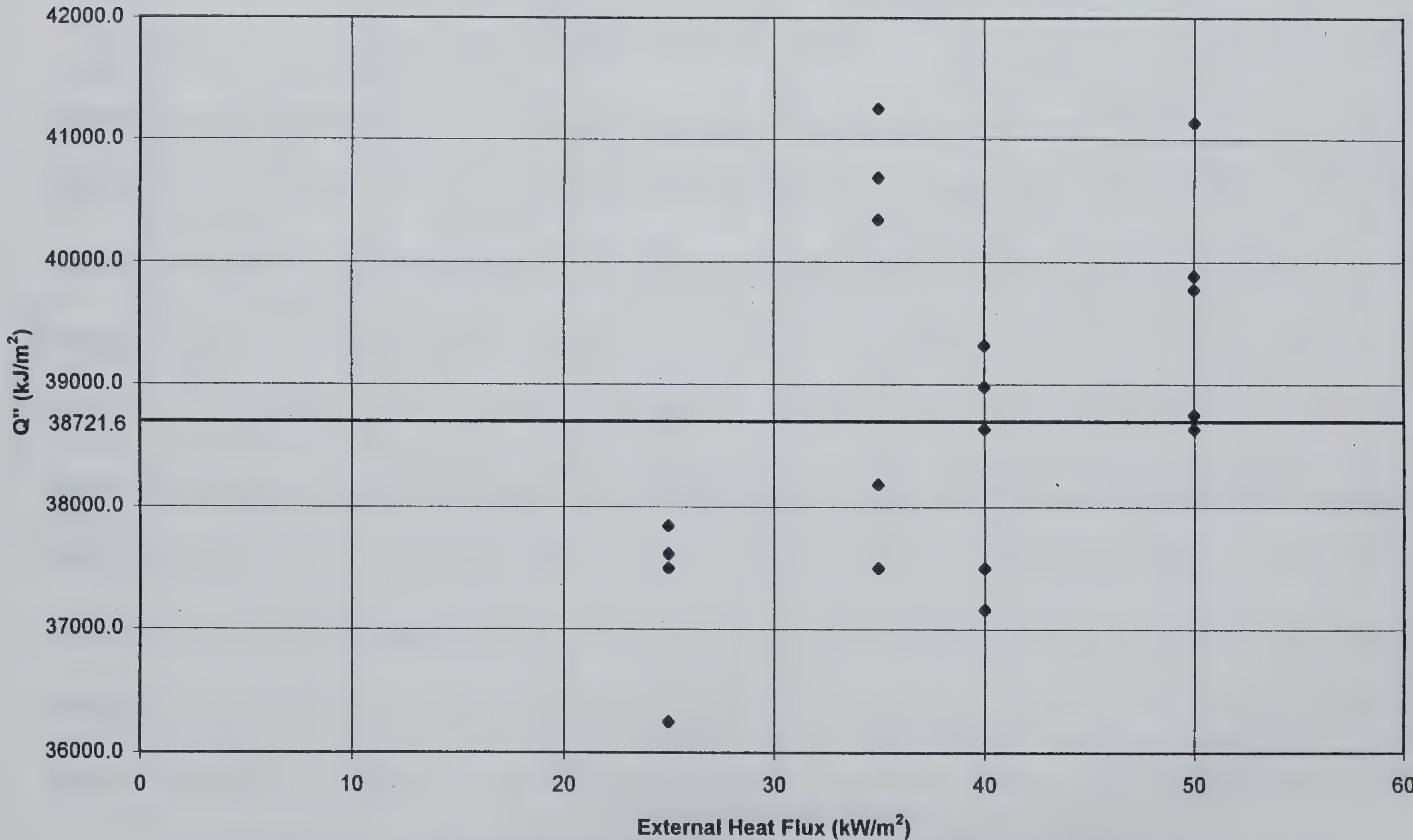
R 4.03 Polyurethane Foam Panel with Aluminum Faced Paper:
Total Heat Evolved vs. External Heat Flux



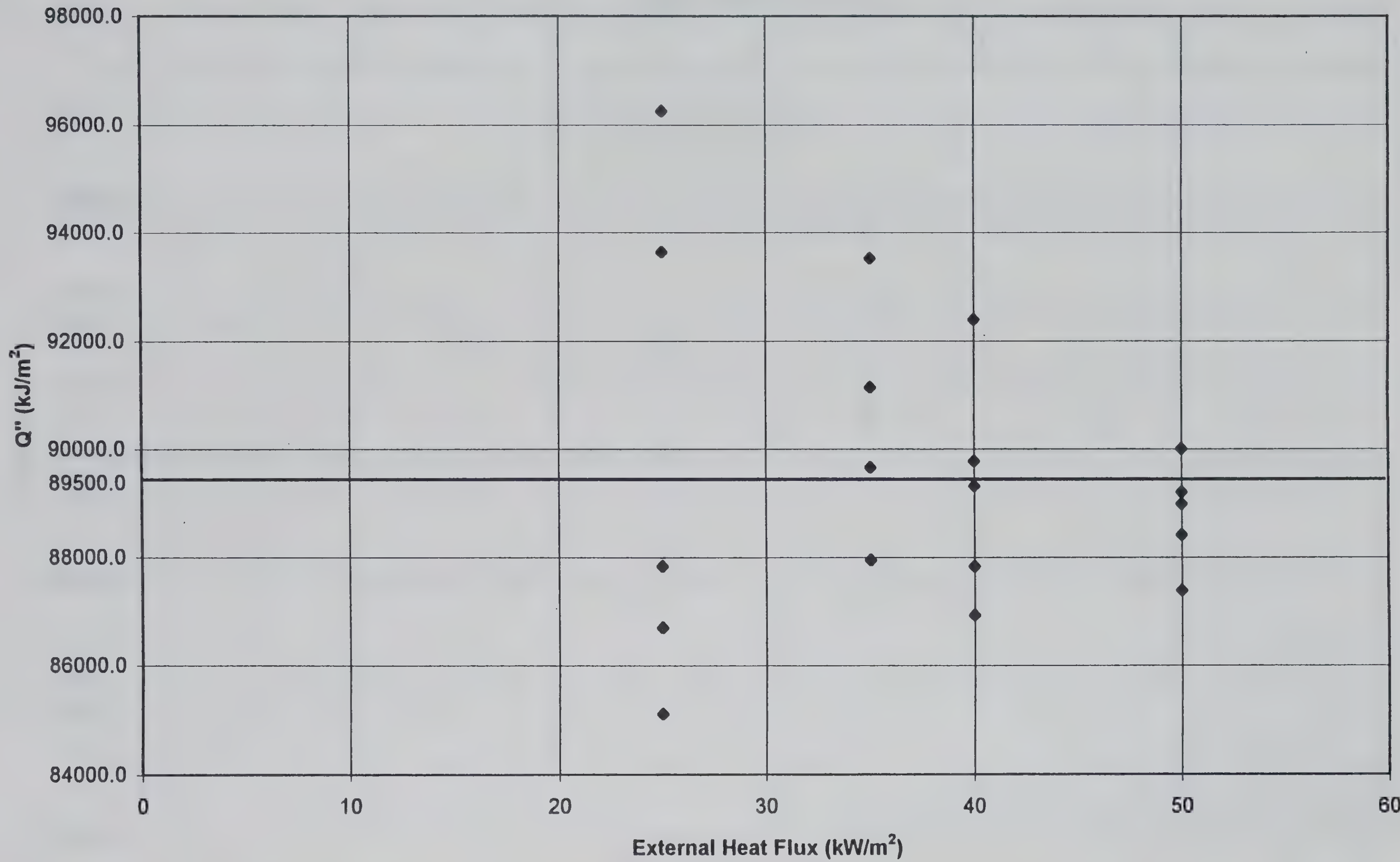
R 4.04 Polyurethane Foam Panel with Paper Backing: Total Heat Evolved vs. External Heat Flux

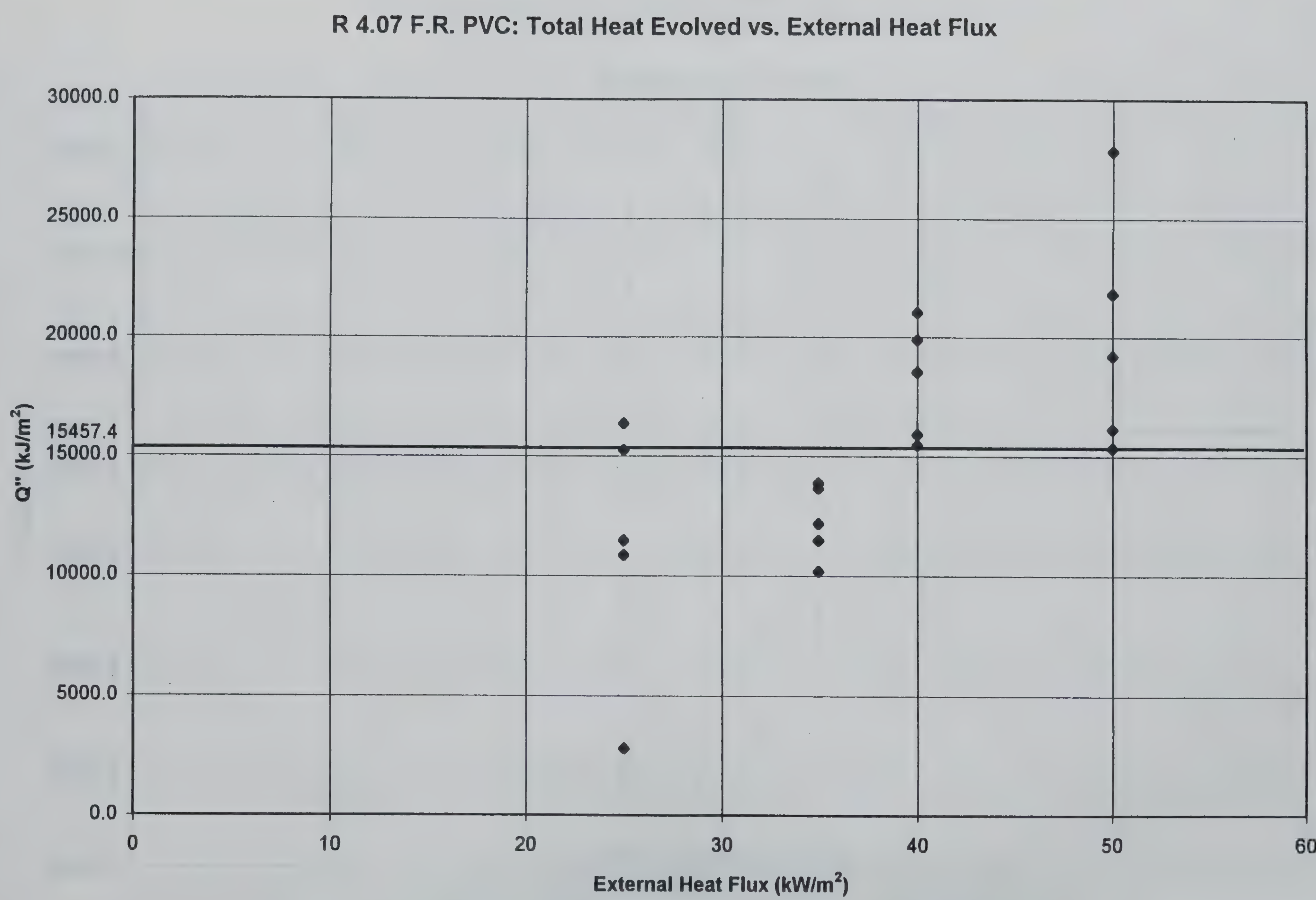


R 4.05 Extruded Polystyrene Board (40 mm):
Total Heat Evolved vs. External Heat Flux

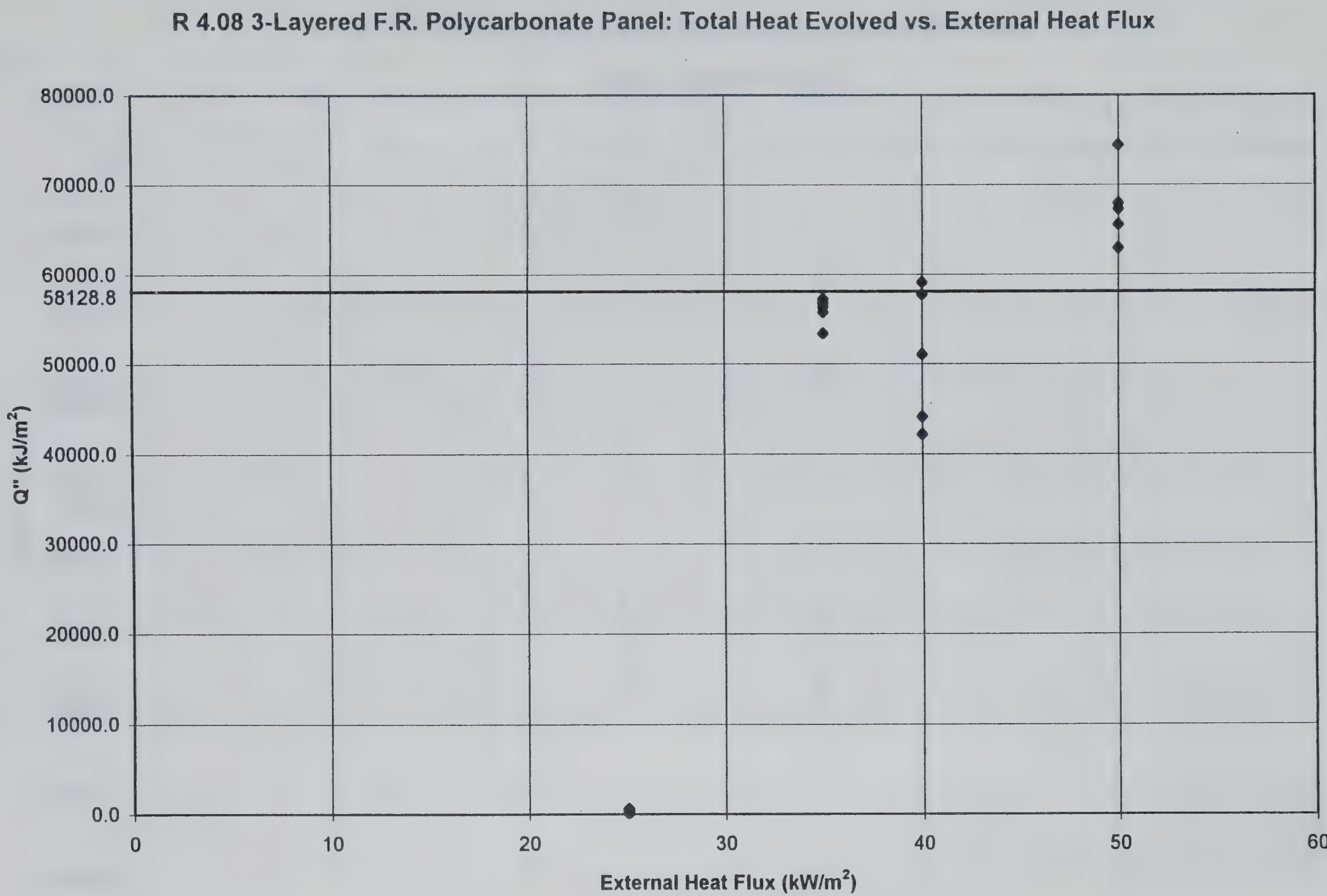


R 4.06 Acrylic Glazing: Total Heat Evolved vs. External Heat Flux



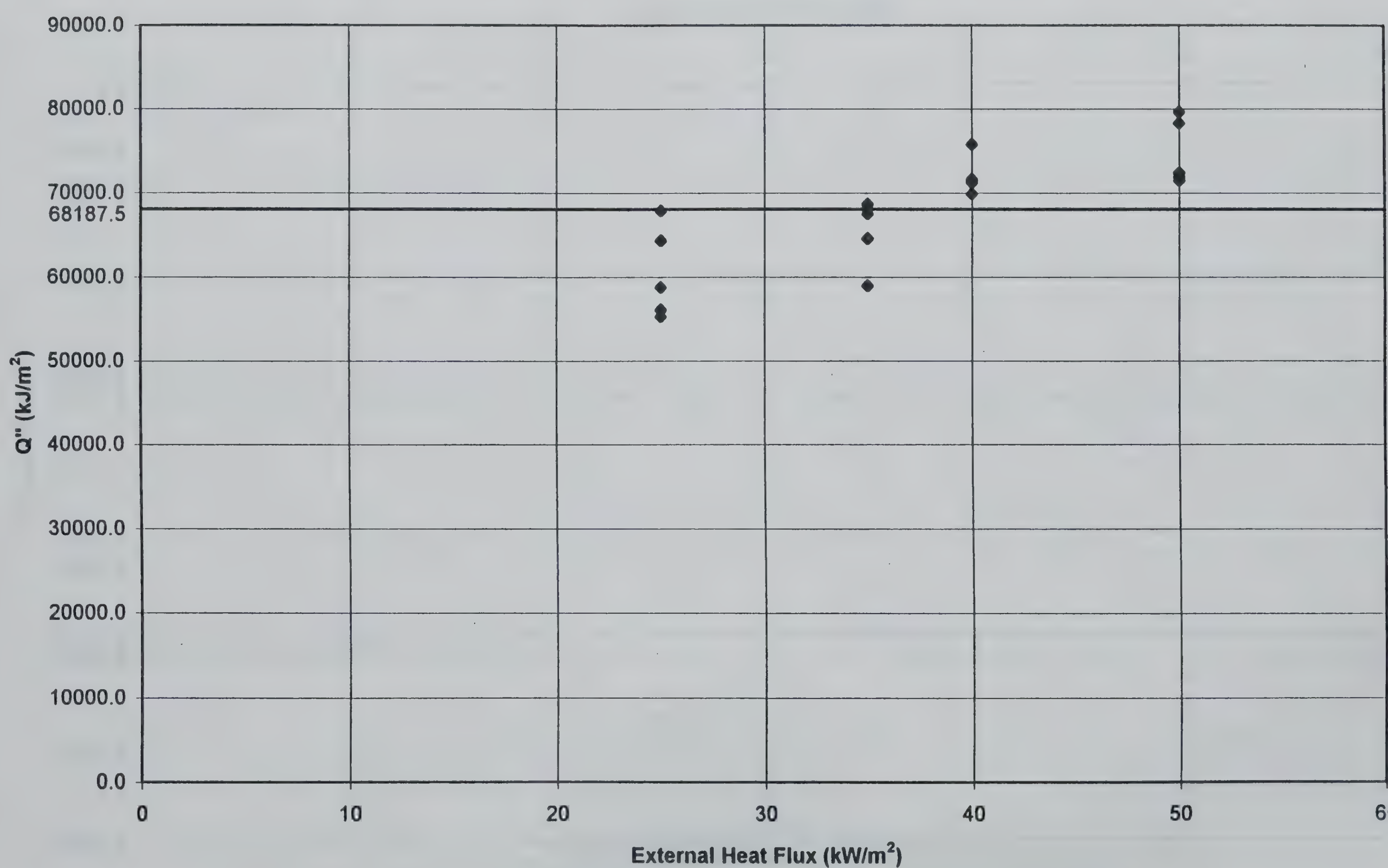


R 4.07 F.R. PVC: Total Heat Evolved vs. External Heat Flux
30000.0
25000.0
20000.0
15457.4
15000.0
10000.0
5000.0
0.0
Q'' (kJ/m2)
0
10
20
30
40
50
60
External Heat Flux (kW/m2)

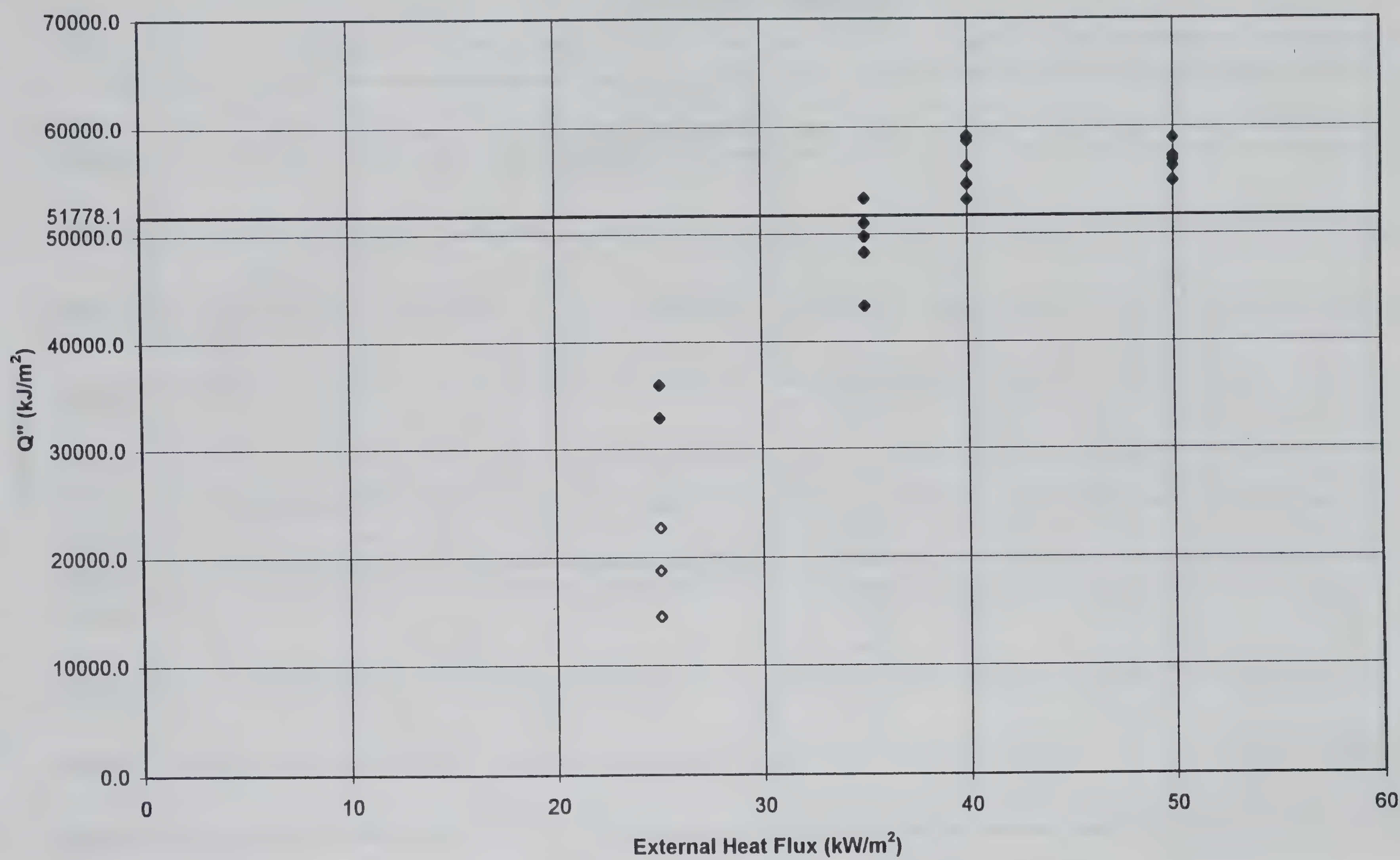


R 4.08 3-Layered F.R. Polycarbonate Panel: Total Heat Evolved vs. External Heat Flux
80000.0
70000.0
60000.0
58128.8
50000.0
40000.0
30000.0
20000.0
10000.0
0.0
Q" (kJ/m2)
0
10
20
30
40
50
60
External Heat Flux (kW/m2)

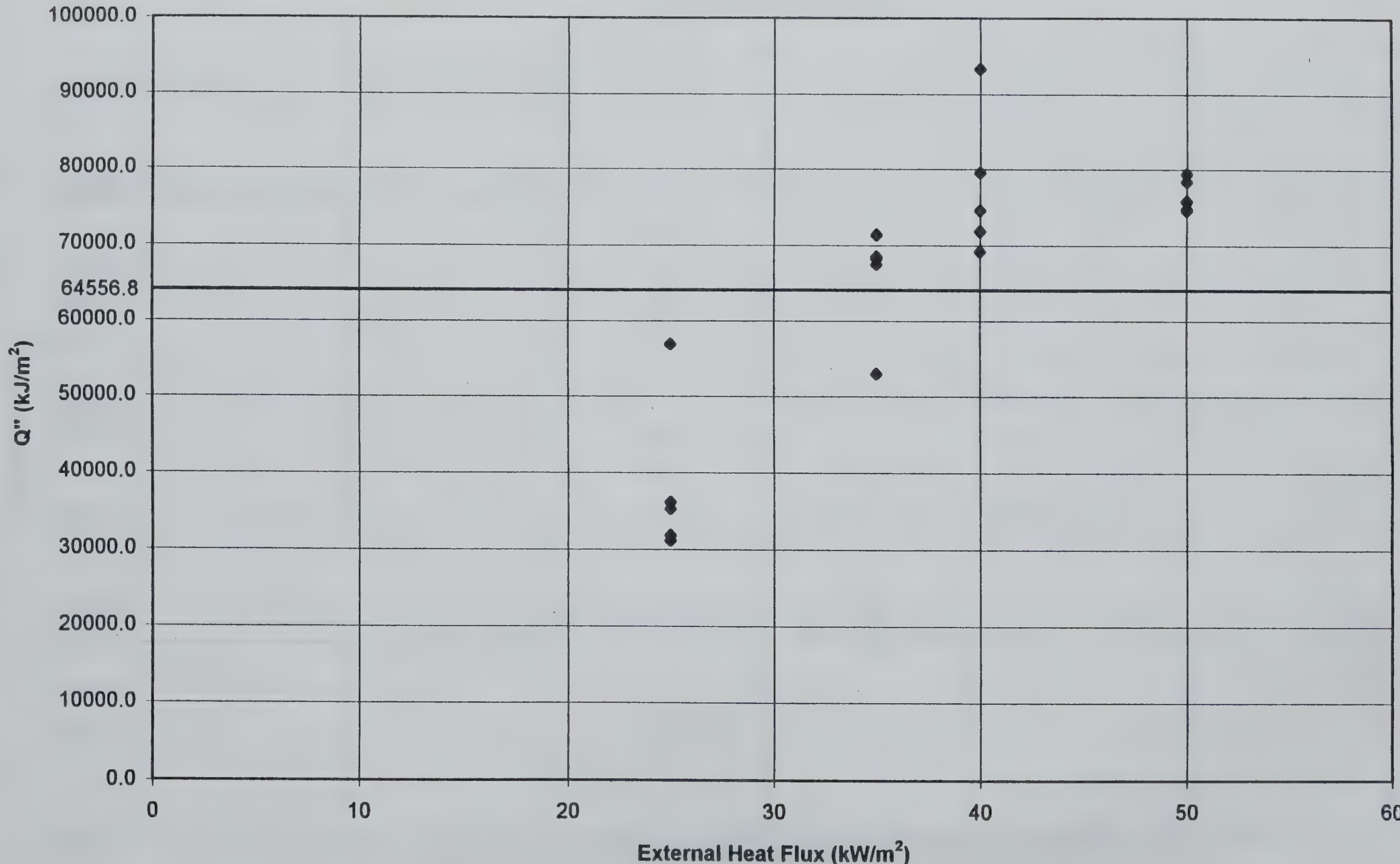
R 4.09 Varnished Massive Timber: Total Heat Evolved vs. External Heat Flux



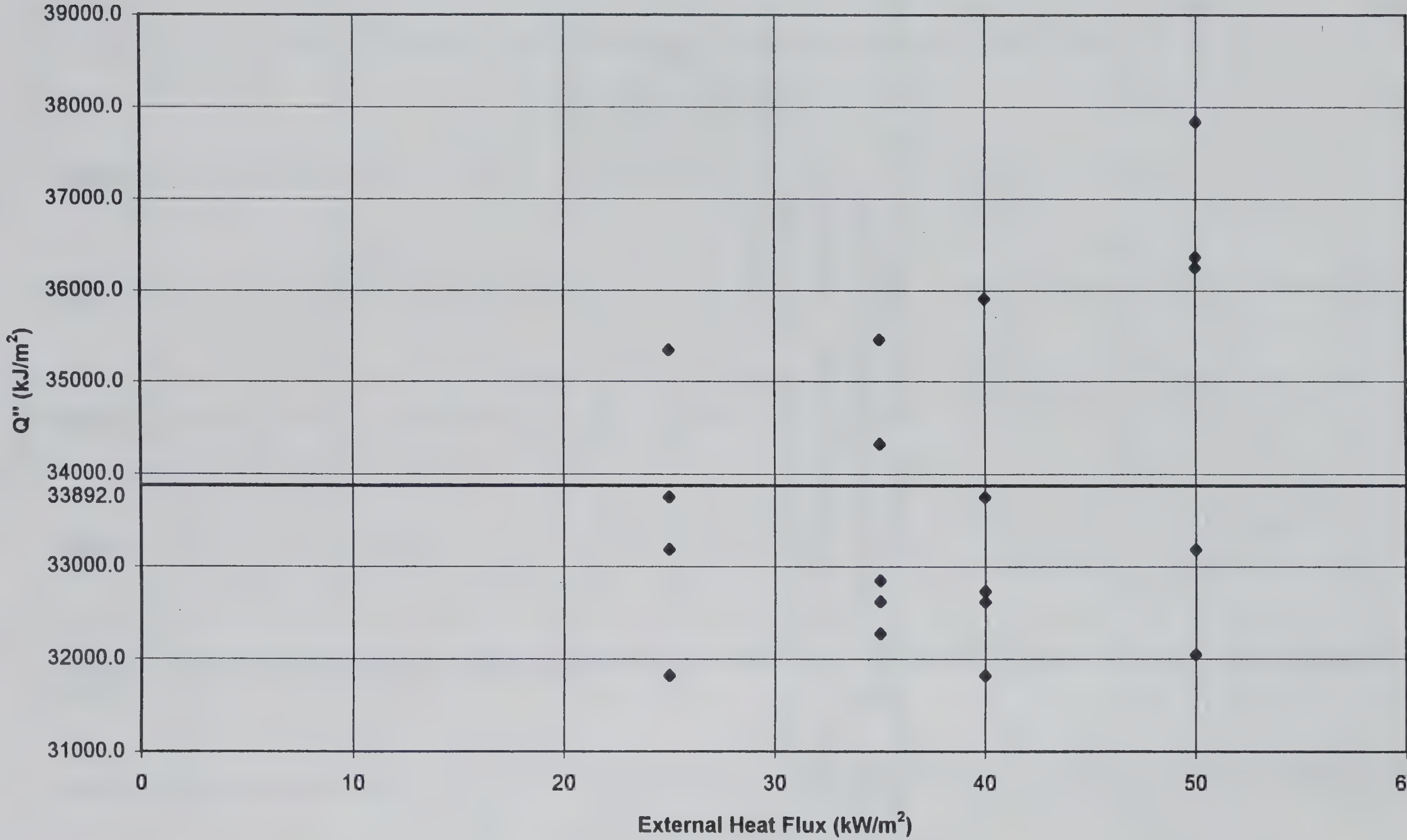
R 4.10 F.R. Plywood: Total Heat Evolved vs. External Heat Flux



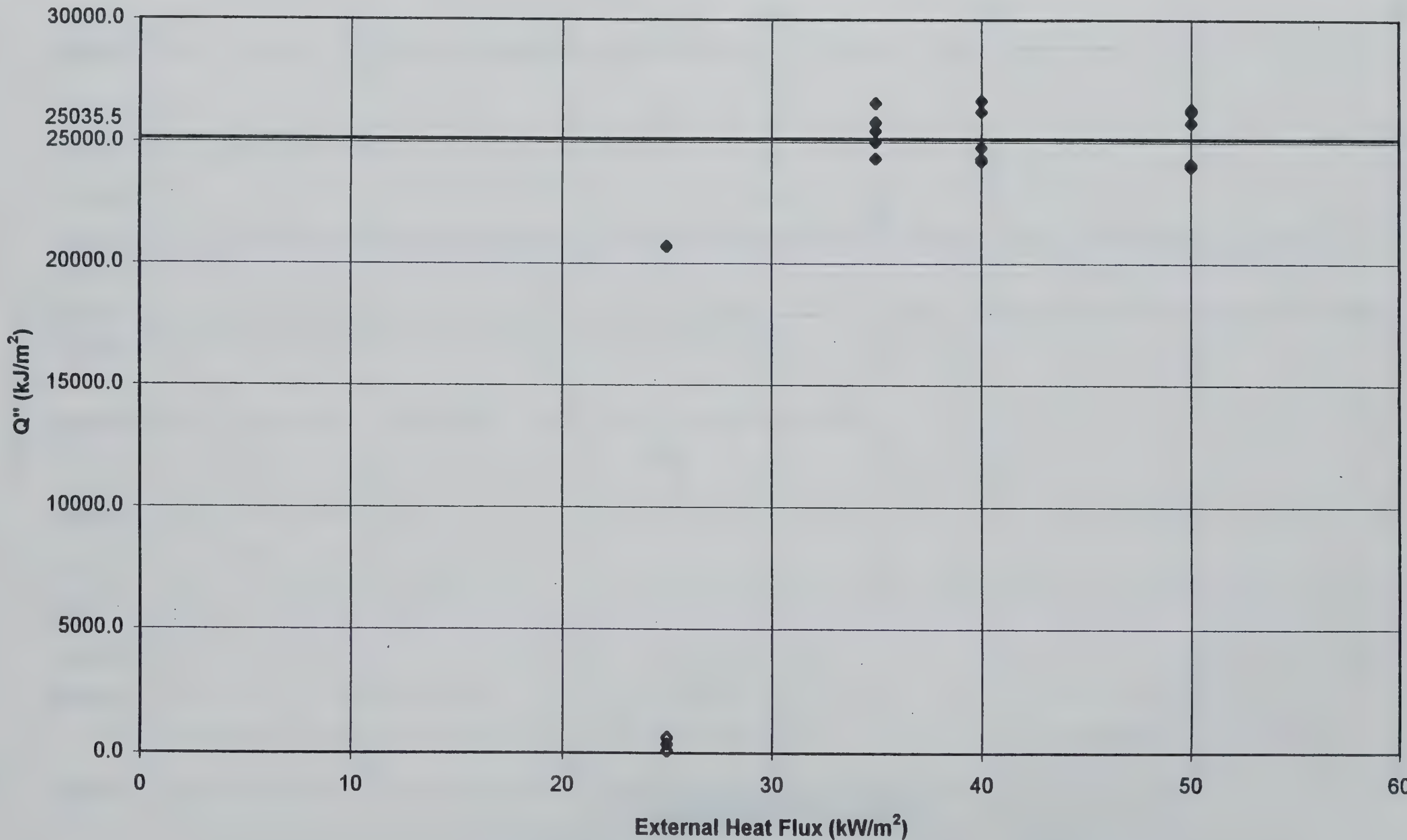
R 4.11 Normal Plywood: Total Heat Evolved vs. External Heat Flux



R 4.20 F.R. Expanded Polystyrene Board (40 mm):
Total Heat Evolved vs. External Heat Flux



R 4.21 F.R. Expanded Polystyrene Board (80 mm):
Total Heat Evolved vs. External Heat Flux



Appendix B – Su, Chen-Hsiang, "Downward and Lateral Flame Spread in Roland Apparatus Phase 5", M. S. Degree Scholarly Paper, Department of Fire Protection Engineering, University of Maryland, college Park, Maryland.

M.S. Degree Scholarly Paper

Downward and Lateral Flame Spread in Roland Apparatus Phase 5

by

Chen-Hsiang Su

July 1997

Instructor : Dr. James G. Quintiere

Department of Fire Protection Engineering
University of Maryland, College Park
MD 20742

TABLE OF CONTENTS

Downward and Lateral Flame Spread in

Roland Apparatus Phase 5

Dr. James G. Quintiere and Chen-Hsiang Su

Abstract

The test data developed from the Roland apparatus phase 5 are analyzed by using a theoretical flame spread model. The Roland apparatus considers a vertically oriented specimen with a 40 kW/m^2 radiant heat source and a 0.42 kW pilot flame. The specimens were divided into 10cm by 10cm areas in order to observe the flame spread on the specimen. During the test the lateral and downward flame developments to these small areas are recorded. By plotting the lateral and downward flame spread velocities versus irradiance, an empirical correlation based on the theoretical model is found to correlate the test data. As a consequence, the material flame heating parameter, Φ , is derived for further application.

NOTATION

b	parameter for thermal response function
c	specific heat
C	negative value of the slope fitting the test data
F(t)	thermal response function
h	surface heat loss coefficient
h_c	convective heat transfer coefficient
k	thermal conductivity
$k\rho c$	thermal inertia of material
$\dot{q}''_{e}$	external radiant heat flux per unit time per unit area
$\dot{q}''_{o,ig}$	critical heat flux for flame spread
$\dot{q}''_{s,min}$	critical heat flux for ignition
t	time
t*	characteristic equilibrium time
T	temperature
T_{ig}	ignition temperature
T_s	surface temperature
T_∞	ambient temperature
V	flame front velocity
x	distance along the test specimen

ρ	density
Φ	flame heating parameter
σ	Stefan-Boltzmann constant

1. INTRODUCTION

In recent years, fire modeling technique has been recognized as a powerful and convenient tool for predicting the real fire phenomena. However, the accuracy and applicability of the fire model strongly depend on the sufficient understanding of related material properties. In this paper, a method of deriving material flame spread parameter Φ from existing test data is proposed. The data used in this paper is offered by the LS Fire Laboratory (Italy) for typical construction materials which contains flame spread data from Roland Apparatus Phase 4 and 5.

The Roland test [1] apparatus is designed to simulate a starting fire under condition 1.) Fire in a corner, and condition 2.) Fire exposure on the wall/specimen of 40 kW/m^2. The fire source is the ISO radiant panel which is positioned in an 35 degree angle to the specimen. The set up gives a similar feed back to the specimen as observed in a real corner fire. The time of ignition and the times which the lateral and downward flame fronts reached each 100mm increment were recorded and mapped.

Under the thermally thick assumption, the theoretical flame spread velocity could be written as $V = \Phi\ (k\rho c)^{-1}\ (T_{ig}-T_s)^{-2}$ [2]. By applying the lateral and downward flame spread data from the Roland test, the parameters Φ, $k\rho c$, and T_{ig} are deduced by analysis. Also a critical surface temperature is determined which continuous spread is not possible. It should be mentioned that the theoretical model does not consider melting, charring, regression, or the fluctuation of T_{ig}, therefor the deduced parameters should be

considered effective only when the realistic flame spread conditions are in well compliance with the assumptions. Inaccuracy of the analysis could be expected for materials with excessive melting and dripping characteristics. However, the analyzing process described in this study provides a consistent approach of relating the test data to theoretical application.

2. THEORETICAL DEVELOPMENT

The basis of the theoretical model is displayed in Fig-1. For the semi-infinite solid under external radiant heat flux, the surface temperature T_s can be given [2] as

$$T_s - T_\infty = \frac{\dot{q}''_e}{h} F(t) \qquad (1)$$

$$\text{where} \quad F(t) = \begin{cases} \dfrac{2h\sqrt{t}}{\sqrt{\pi k \rho c}} , & t \rightarrow \text{small} \\ 1 , & t \rightarrow \text{large} \end{cases} \qquad (2)$$

In the above equations, $\dot{q}''_e$ is the external radiant heat flux, T_∞ is the ambient and initial temperature, h is the surface heat loss coefficient, and $F(t)$ is a function of time and the thermal properties of the solid.

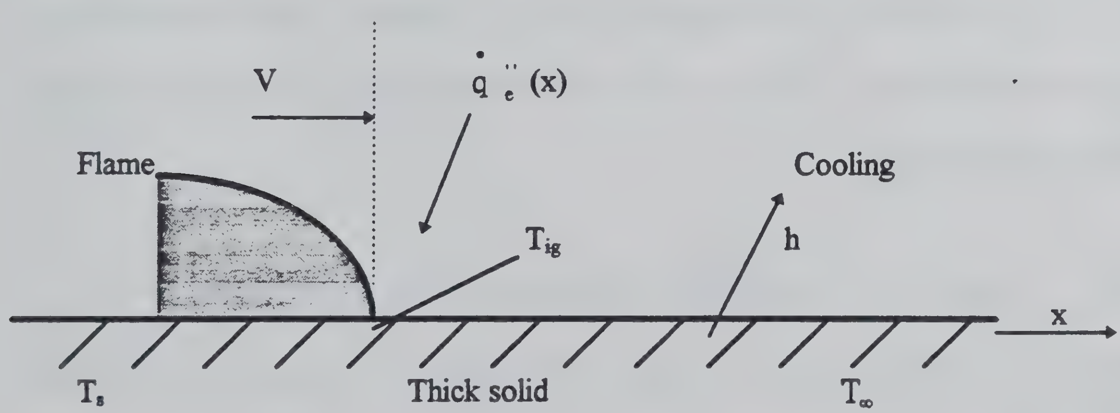


Fig - 1 Flame spread model

For the steady state condition after long heating time, $F(t) \to 1$, equation (1) can be rewritten as

$$\dot{q}''_e = h_c(T_s - T_\infty) + \sigma(T_s^4 - T_\infty^4) \equiv h(T_s - T_\infty) \qquad (3)$$

where h_c is the convective heat transfer coefficient.

By substituting $T_s = T_{ig}$ into equation (3), the critical heat flux for ignition $\dot{q}''_{o,ig}$ could be found as

$$\dot{q}''_{o,ig} = h_c(T_{ig} - T_\infty) + \sigma(T_{ig}^4 - T_\infty^4) \equiv h(T_{ig} - T_\infty) \qquad (4)$$

Based on the equation (1) to (4), an empirical result has been found to describe the ignition data. It can be written as

$$\frac{\dot{q}''_{o,ig}}{\dot{q}''_e} = F(t) = \begin{cases} b\sqrt{t} & , \ t \le t^* \\ 1 & , \ t \ge t^* \end{cases} \qquad (5)$$

where b is a constant for a given material, and t^* is the characteristic time indicating the thermal equilibrium for $F(t^*) = 1$. By comparing equation (2) and (5), the following relation could be found.

$$b = \frac{2h}{\sqrt{\pi k \rho c}} \qquad (6)$$

Equation (6) could be used to determine $F(t)$ while h and $k\rho c$ for a certain material are known.

The flame spread velocity V is expressed [2] as

$$V = \frac{\Phi}{k\rho c\,(T_{ig} - T_s)^2} \tag{7}$$

where Φ is the flame heating parameter for a given material. Equation (7) can also be written as

$$V^{-1/2} = \sqrt{\frac{k\rho c}{\Phi}}\,(T_{ig} - T_s) \tag{8}$$

By substituting equation (3) and (4) into equation (8), the equation becomes

$$V^{-1/2} = \sqrt{\frac{k\rho c}{\Phi}}\left(\frac{1}{h}\right)\left[\dot{q}''_{ig} - \dot{q}''_{e}F(t)\right]$$

$$= \left(\sqrt{\frac{1}{\Phi}}\right)\left(\frac{2}{\sqrt{\pi}}\right)\left(\frac{\sqrt{\pi k\rho c}}{2h}\right)\left[\dot{q}''_{ig} - \dot{q}''_{e}F(t)\right]$$

$$= \left(\sqrt{\frac{1}{\Phi}}\right)\left(\frac{2}{\sqrt{\pi}}\right)\left(\frac{1}{b}\right)\left[\dot{q}''_{ig} - \dot{q}''_{e}F(t)\right]$$

$$= C\left[\dot{q}''_{ig} - \dot{q}''_{e}F(t)\right] \tag{9}$$

where $\Phi = (4/\pi)\,(C\,b)^{-2}$ (10)

and $-C$ is the slope observed from the test data plot of $V^{-1/2}$ versus $\dot{q}''_{e}F(t)$.

3. THE ROLAND TEST PHASE 5 APPARATUS

3.1 DESCRIPTION

The Roland test apparatus is designed to simulate a starting corner fire as shown in Fig-2.

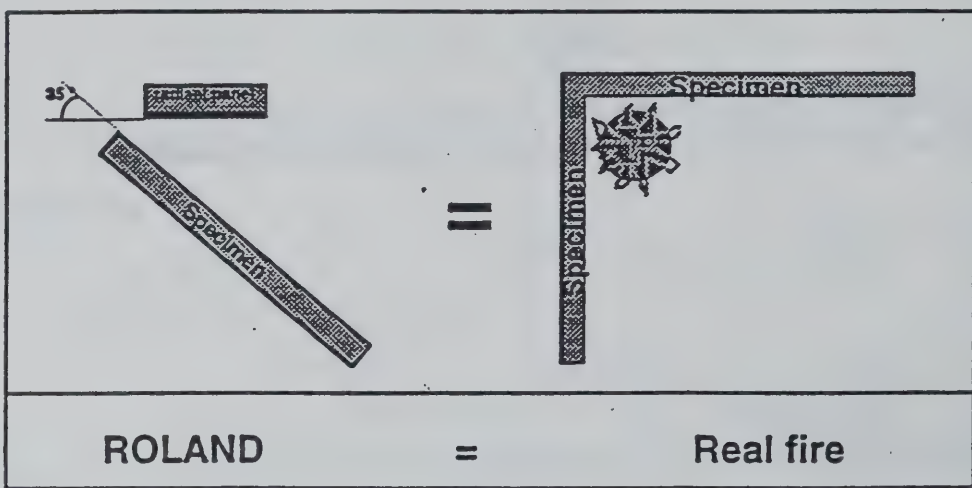


Fig -2 Concept of Roland Apparatus

The radiation panel gives a constant output of 40 kW/m which together with the 0.42 kW pilot flame create a stable environment for testing. The specimen to test is 1m by 1.5 m and is placed in a specimen holder which again is placed on a electrical driven trolley. The moving of the test specimen is controlled from outside the test room so as to ensure stable test conditions.

The test specimen is placed on top of an insulated steel tray to capture the eventually dripping from the burning specimen. Capturing of dripping is important for the development of the fire and is therefor visually observed and recorded.

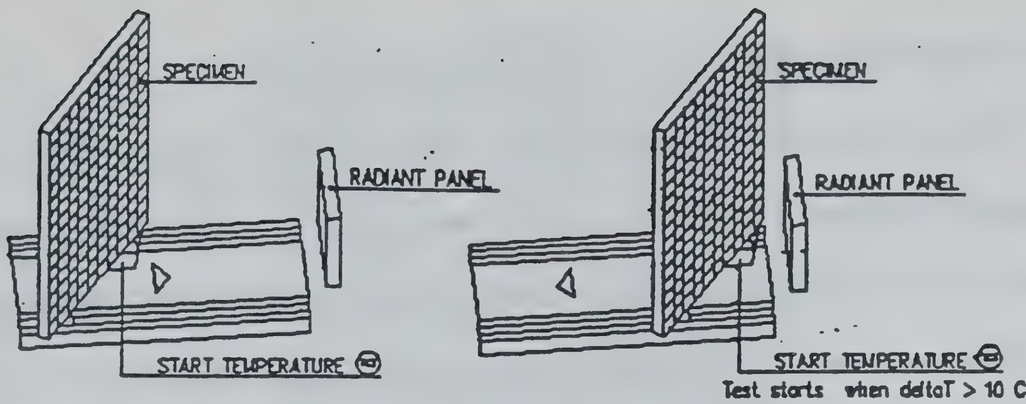
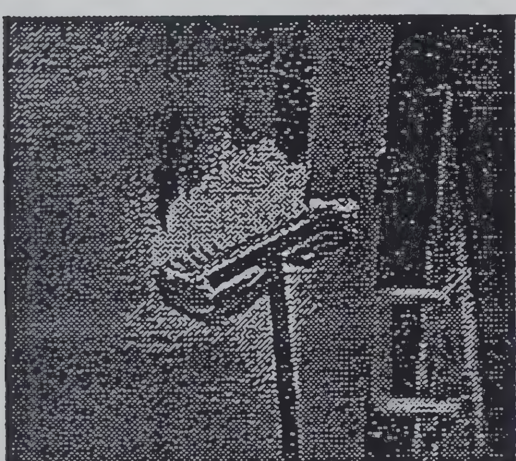


Fig - 3 Test Apparatus Setup

A movable pilot flame is mounted in front of the radiation panel to ignite the combustible gasses from the test products. The length of the flame is approximately 25 mm and they are not touching the surface of the product as shown in Fig - 4. If the product melts or expands, the pilot flame could move with the surface of the product so as to simulate the real fire condition.



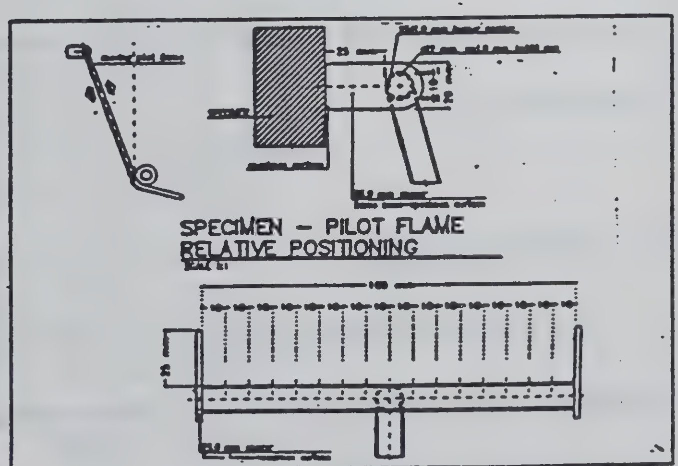


Fig - 4 The Pilot Flame

3.2 TEST CONDITIONS

The room for Roland apparatus is 19 m^2 in area and has a volume of 74 m^3. An extraction hood below the ceiling covering the specimen and the radiant panel is mounted in the room. The air change rate is 14.5 times/hr. 2 symmetrically placed openings at the end of the room serve the air and the air velocity was kept under 0.1 m/s so as to avoid any turbulence which might affect the burning behavior of the test specimen.

3.3 INSTRUMENTATION

The design of the extraction duct, the measuring device and the analyzers follow the specifications from the ISO 9705 Room Corner. The result was logged into a computer each 6 seconds.

3.4 CALIBRATION OF THE RADIANT PANEL

In order to secure the agreed level of the thermal attack of 40 kW/m^2 in an area of 300 cm on the specimen, the heat flux distribution was checked frequently and the result was shown in Fig - 5 .

3.5 TEST SPECIMEN

The test specimen was prepared with a size of 1000 by 1500 mm, as in Fig - 6. The specimen was marked and divided into 100 by 100 mm areas. For a more detail dimension of the setup, see Appendix .

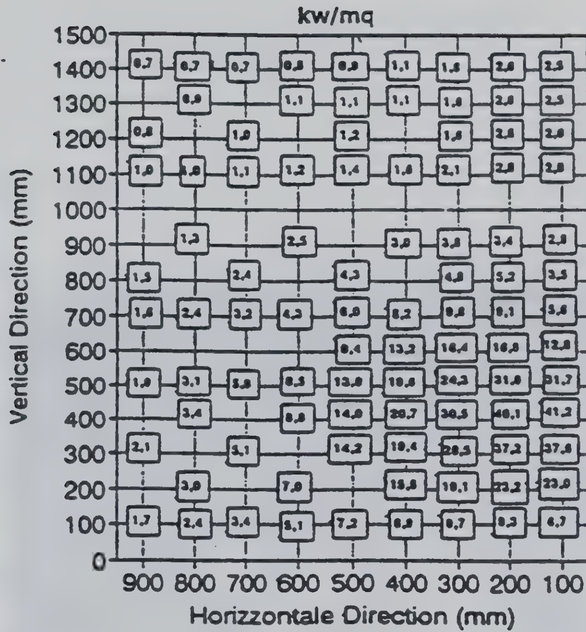


Fig - 5 Roland Phase 5 Heat Flux Calibration Diagram

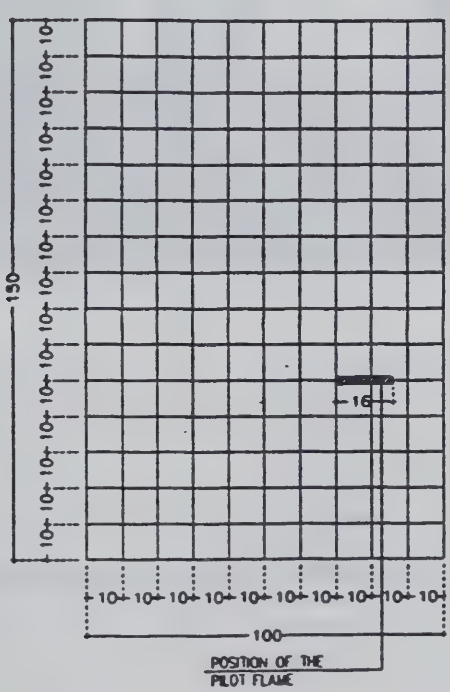


Fig - 6 Dimension of the test specimen

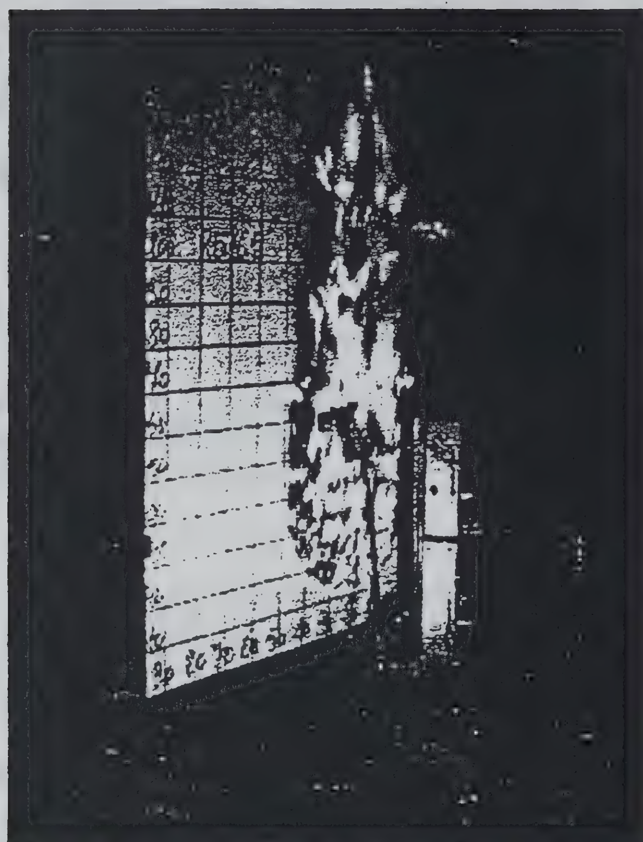


Fig - 7 Illustration of the test apparatus

4. ANALYSIS PROCEDURE

4.1 FLAME SPREAD TEST

During the testing period, the measurements and observations include:

- Maximum temperature rise in the hood,
- Production of the heat release,
- Light intensity,
- Time to ignition,
- Time for flame front to reach 100 mm increment in upper, lateral, and downward direction,
- Duration of flaming,
- Critical flux,
- Dipping, burned area, damaged area, and weight loss.

A sample flame spread record of the test result is shown in Fig - 8.

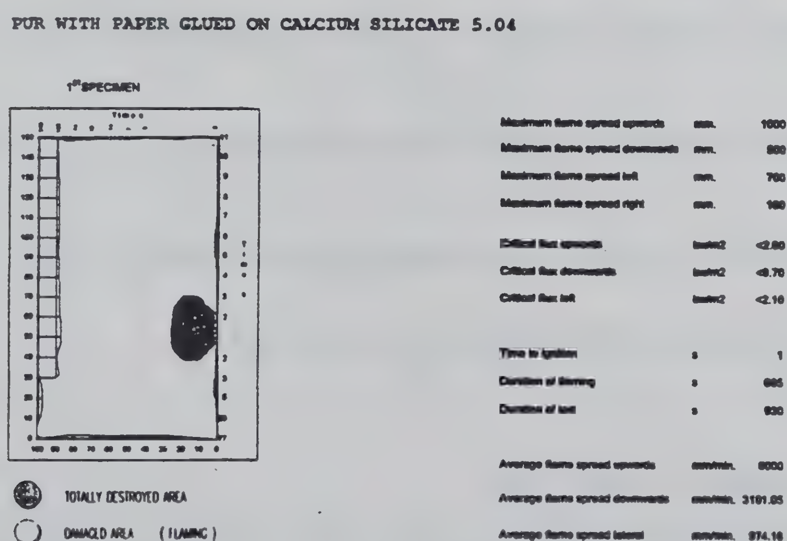


Fig - 8 A sample record of the test result

4.2 DATA ANALYSIS

(1) Obtain $k\rho c$ and T_{ig} from Roland apparatus phase 4

From a separate study on the test result of Roland apparatus phase 4 test data [3], the $k\rho c$ and T_{ig} for several materials were derived. Those derived values were used as input parameters for this study.

(2) Compute flame front velocity V

By applying a running three-point least square fit , as in equation (11), to the measured flame front position-time (x,t) data, the flame spread velocity could be found.

$$V = \frac{\Sigma tx - \frac{\Sigma t \, \Sigma x}{3}}{\Sigma t^2 - \frac{(\Sigma t)^2}{3}} \tag{11}$$

(3) Calculate the surface heat loss coefficient h and critical heat flux $\dot{q}''_{o,ig}$

Since T_{ig} is known, equation (4) would than gives the value of $\dot{q}''_{o,ig}$. The value of h_c is chosen to be 15 W/m^2, which is similar to the LIFT test [4]. After $\dot{q}''_{o,ig}$ was found, h is then derived by applying the equation (4).

(4) Calculate the parameter b and $F(t)$

With the $k\rho c$ and T_{ig} previously derived from Roland apparatus phase 4, the parameter b could be found by applying equation (6). For any given t , F(t)

is then determined by using equation (5).

(5) Find the slope $-C$

As shown in Fig - 9, by plotting $V^{-1/2}$ versus $\dot{q}''_e F(t)$, the slope $-C$ can be estimated either mathematically or manually. The fitting line was forced to pass trough the point $\dot{q}''_{o,ig}$ so as to obtain a more consistent correlation.

(6) Compute the flame spread parameter Φ

After the value C was determined in the previous step, the flame spread parameter Φ is finally determined by using equation (10).

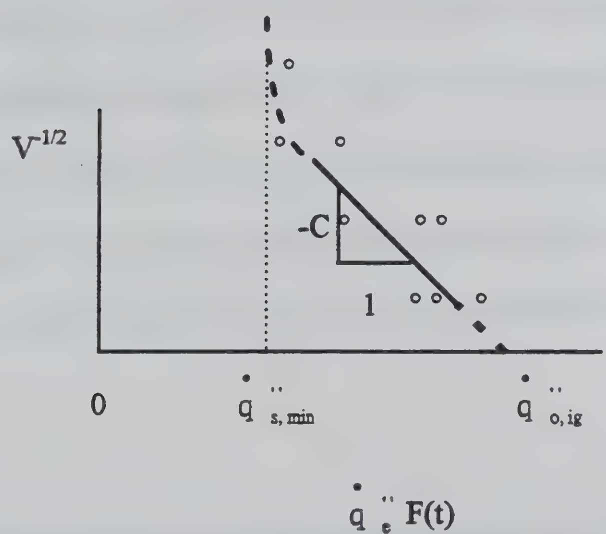


Fig - 9 Estimation of the slope $-C$ from derived data plot

5. RESULTS

Based on the proposed analysis procedure, totally 13 materials were analyzed and a summary of the results is sown in Table - 1. Detail calculating for the materials that flame spread were observed are shown in Table - 2 to Table - 19. The tables show the results for varied external irradiances for no pre-heat conditions where the solid line indicate the slope. It should be noticed that the high end of the solid line is near extinction where chemical kinetic dominates and heat loss phenomena is suspected to influence the flame spread speed. The low end, on the other hand, is near ignition where spread velocities are high and ignition phenomena can effect flame spread. Therefor, scattered data points at the both ends of the solid line could be expected.

For the wooden material group, 5-04, -09, -10, -11, the test data correlate well with the fitting lines, and the magnitude of derived flame heating parameters are within reasonable range. For the thermal plastic group, 5-05, -07, -08, -12,-13, test data were dispersed and did not fit well with a straight line. There were no flame spread at all for three materials, 5-01, -02,-03. There is also no test data for material 5-06 due to melting and unusual flame spread,.

While the properties of thermal plastic materials do not tend to follow the theoretical assumptions as described in the introduction, it is not surprised that the data were dispersed. There are two possible major effects that caused the difficulties of correlating the data, one is the melting effect, another is the tray effect. When heating up the products in this group,

the flame spread velocities are depending on the melting-away patterns, dripping levels, and the continuation of the burning of the droplets after they have been collected in the tray. For cases that the data were obviously influenced by both of the two effects, two Φs were derived for reference.

It is unusual that the flame spread downwards but not laterally for material 5-08. This could be caused by the distortion of the specimen that blocked the flame propagation during heating up. In the general, since there are more measuring points at the lateral direction, the resolutions are better than the downward, and thus the estimation of Φ is more accurate. For materials that only few test data are available, it is difficult to achieve accurate analysis results. Further investigation and experiments are required to reveal the related properties of those products.

6. CONCLUSIONS

The analysis and results of this study illustrate a well defined procedure of deriving material flame spread properties from Roland test data. The flame heating parameters found in this study can be used either in advanced fire models or as the performance indexes of material fire resistance.

A spread sheet program for analyzing the Roland test data is successfully built. With proper input data, the spread sheet will execute all require calculations and generate related data plots. Since the diagrams are directly linked to the data cells in the spread sheet, the estimation of the slopes could be done in few trial-error steps.

Although only the test data of Roland apparatus phase 5 are analyzed in this study, the concept of proposed method is not limited to the specific apparatus. With a little modification of the analysis procedure, the method or the spread sheet program could be applied to similar test apparatus and give satisfied results.

7. REFERENCES

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Table - 1 Summary of Analysis Results

Description	Tig (°C)	$k \rho c$ ($kW^2m^{-4}°K^{-2}S$)	Φ Lateral (kW^2/m^3)	Φ Downward (kW^2/m^3)	Ts, min (°C)
+ 5-01 FR Chip Board	505	4.02	0	0	505
+ 5-02 Gypsum Board	515	0.55	0	0	515
+ 5-03 Pur + Alufoil	---	---	0	0	---
++ 5-06 Acrylic	195	2.96	---	---	195
5-05 XPS 40mm	275	1.98	(273.0*) 1.2	33	75
5-07 PVC	415	1.31	0.2	6.8 **	350
5-08 Layered PC	495	1.47	0	520.5	165
5-04 Pur + Paper	250	0.2	8.7	8.7	80
5-09 Massive Timber	330	0.53	6.9	25.3	80
5-10 FR Plywood	480	0.106	0.7	1.1	200
5-11 Std. Plywood	290	0.634	2.2	3.6	145
5-12 FR EPS 40mm	295	1.59	(513.2 *) 4.2	200.5 **	75
5-13 FR EPS 80mm	490	0.557	7.1	5.6 **	75

Notes:

"+" : No flame spread was observed.

"++" : Not able to test due to melting and unusual flame spread.

"*" : Tray effect suspected.

"**" : Not accurate due to scattered test data.

Table - 2 Roland 5-04 (Pur with Paper Glued on Calcium Silicate) Lateral Flame Spread

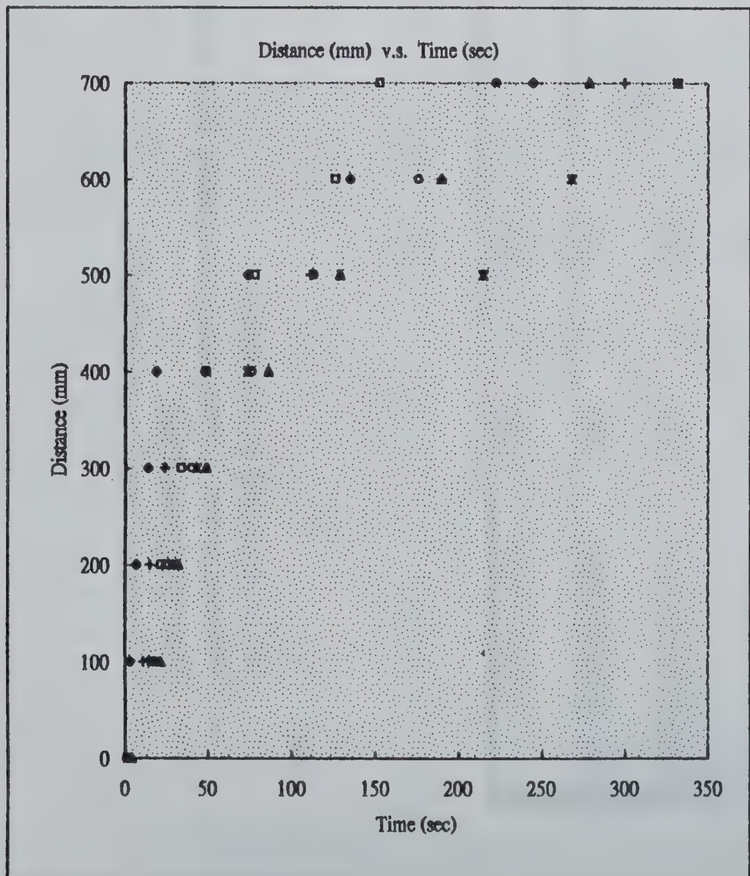
q" (kw/m^2)	Dis.(mm)	#1 (sec)	#2	#3	#4	#5	#6	q" F1(t)	q" F2(t)	q" F3(t)	q" F4(t)	q" F5(t)	q" F6(t)	V1	V2	V3	V4	V5	V6	1/sqrt(V1)	1/sqrt(V2)	1/sqrt(V3)	1/sqrt(V4)	1/sqrt(V5)	1/sqrt(V6)
24.3	0	1	2	4	3	2	2	2.0	2.8	3.9	3.4	2.8	2.8	---	---	---	---	---	---	---	---	---	---	---	---
19.6	100	3	16	21	11	17	19	2.7	6.3	7.2	5.2	6.5	6.9	32.14	9.49	7.04	16.07	7.38	8.08	0.18	0.32	0.38	0.25	0.37	0.35
13	200	7	22	32	15	29	25	2.8	4.9	5.9	4.1	5.6	5.2	17.74	10.71	7.04	14.66	7.68	8.97	0.24	0.31	0.38	0.26	0.36	0.33
8.5	300	14	34	49	24	43	40	2.6	4.0	4.8	3.4	4.5	4.3	16.51	7.38	3.54	5.67	4.24	3.71	0.25	0.37	0.53	0.42	0.49	0.52
5	400	19	49	86	48	74	76	1.8	2.8	3.7	2.8	3.5	3.5	2.71	4.40	2.50	2.15	1.02	2.74	0.61	0.48	0.63	0.68	0.99	0.60
3.1	500	74	78	129	111	215	113	2.1	2.2	2.8	2.6	3.1	2.7	1.72	2.55	1.90	1.40	0.96	1.96	0.76	0.63	0.72	0.84	1.02	0.72
1.9	600	135	126	190	190	268	176	1.8	1.7	1.9	1.9	1.9	1.9	1.14	2.60	1.32	1.05	1.70	1.81	0.94	0.62	0.87	0.98	0.77	0.74
---	700	245	153	279	300	332	223	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---

$k \cdot \rho \cdot c$	T.ig (K)	q",crit	h	b	t* (sec)	q"s,min	Ts,min (K)
0.199	523	7.2	0.032	0.081	154	1.2	345

Slope (Auto) = -0.15

Slope (Manual): -0.15

Φ-kw²/m³: 8.7



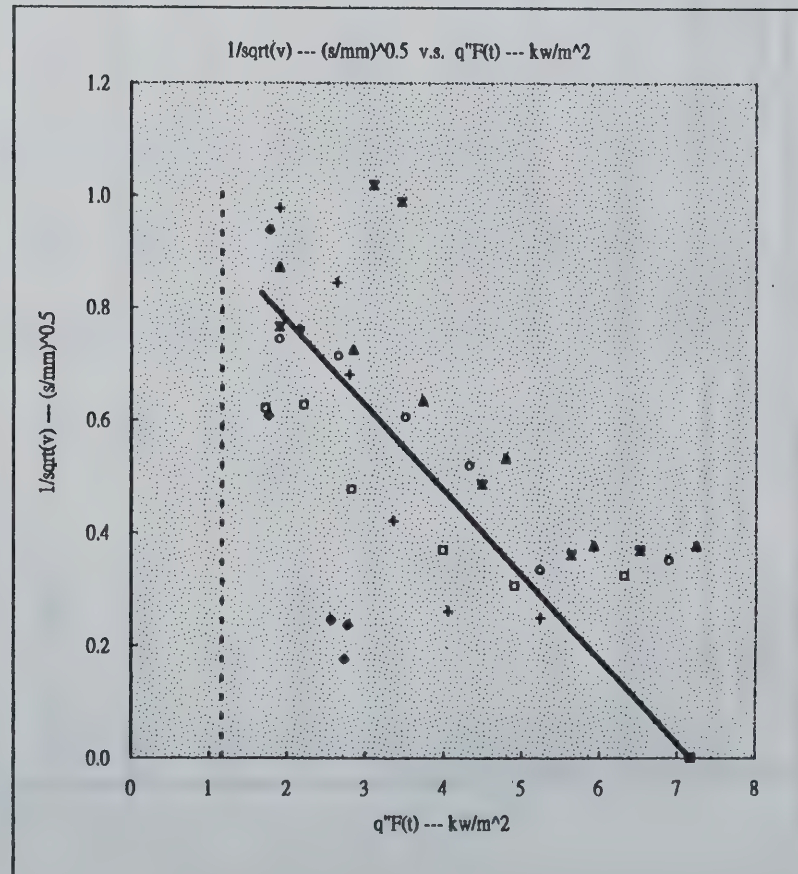
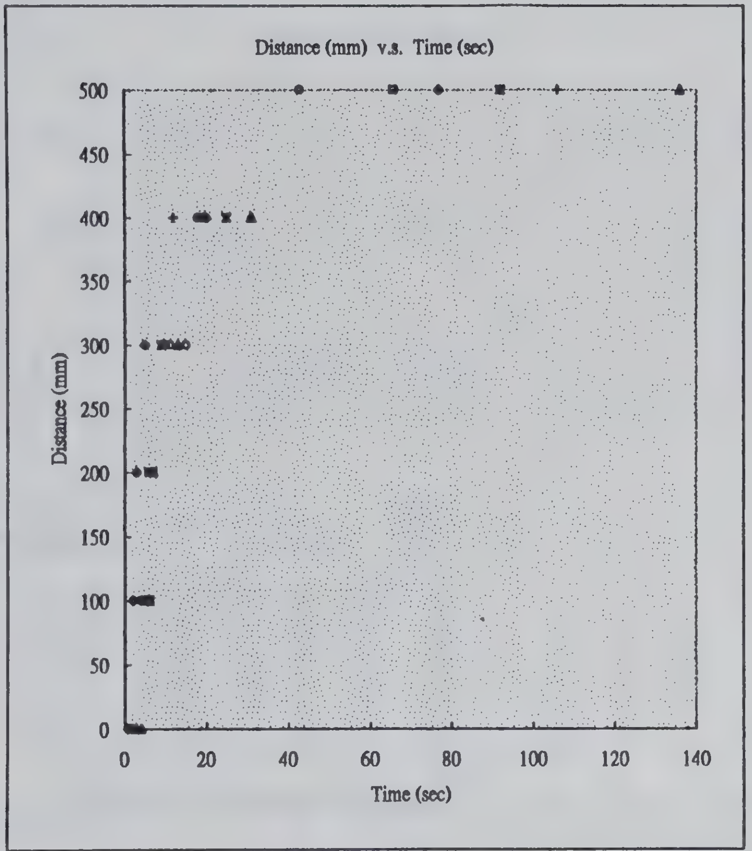


Table - 3 Roland 5-04 (Pur with Paper Glued on Calcium Silicate) Downward Flame Spread

q" (kw/m^2)	Dis.(mm)	#1 (sec)	#2	#3	#4	#5	#6	q" F_1(t)	q" F_2(t)	q" F_3(t)	q" F_4(t)	q" F_5(t)	q" F_6(t)	V_1	V_2	V_3	V_4	V_5	V_6	1/sqrt(V_1)	1/sqrt(V_2)	1/sqrt(V_3)	1/sqrt(V_4)	1/sqrt(V_5)	1/sqrt(V_6)
31.0	0	1	2	4	3	2	2	2.5	3.5	5.0	4.3	3.5	3.5	---	---	---	---	---	---	---	---	---	---	---	---
40.1	100	2	6	6	5	5	4	4.6	7.9	7.9	7.2	7.2	6.5	100.0	35.7	64.3	64.3	46.2	50.0	0.10	0.17	0.12	0.12	0.15	0.14
37.2	200	3	7	7	6	6	6	5.2	7.9	7.9	7.3	7.3	7.3	64.3	35.7	24.4	35.7	46.2	16.0	0.12	0.17	0.20	0.17	0.15	0.25
23.2	300	5	11	13	10	9	15	4.2	6.2	6.7	5.9	5.6	7.2	9.8	16.1	7.7	32.1	9.1	15.4	0.32	0.25	0.36	0.18	0.33	0.25
9.3	400	20	19	31	12	25	18	3.4	3.3	4.2	2.6	3.7	3.2	2.5	3.1	1.4	1.6	2.1	5.9	0.63	0.57	0.85	0.79	0.68	0.41
---	500	77	66	136	106	92	43	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---

$k \cdot \rho \cdot c$	T,ig (K)	q",crit	h	b	t* (sec)	q"s,min	Ts,min (K)	Slope (Auto) =	Slope (Manual)	Φ — kw²/m³
0.199	523	7.2	0.032	0.081	154	1.2	345	-0.15	-0.15	8.7



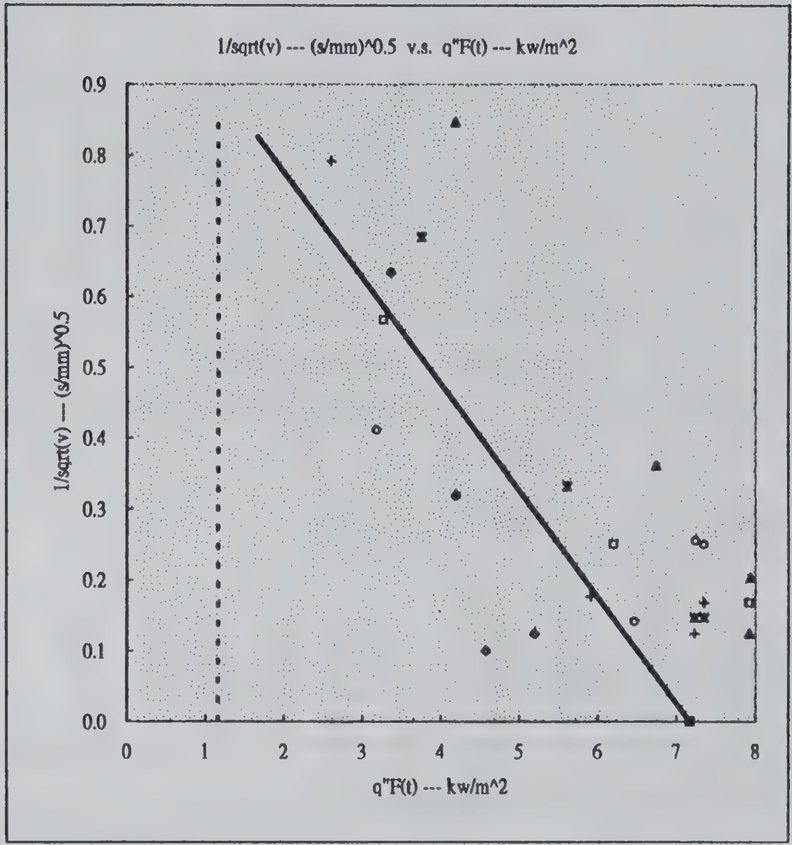


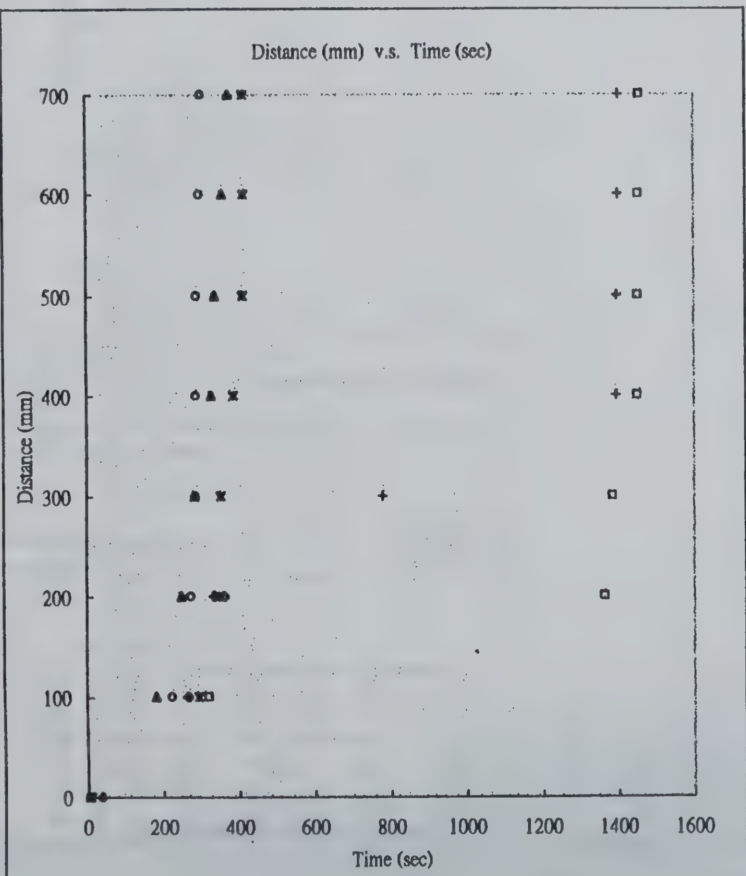
Table - 4 Roland 5-05 (XPS 40mm) Lateral Flame Spread

q" (kw/m^2)	Dis.(mm)	#1 (sec)	#2	#3	#4	#5	#6	q" F1(t)	q" F2(t)	q" F3(t)	q" F4(t)	q" F5(t)	q" F6(t)	V_1	V_2	V_3	V_4	V_5	V_6	1/sqrt(V_1)	1/sqrt(V_2)	1/sqrt(V_3)	1/sqrt(V_4)	1/sqrt(V_5)	1/sqrt(V_6)
24.3	0	37	6	5	7	7	5	4.0	1.6	1.5	1.7	1.7	1.5	---	---	---	---	---	---	---	---	---	---	---	---
19.6	100	268	321	182	265	294	224	8.7	9.5	7.1	8.6	9.1	7.9	0.58	0.13	0.77	0.55	0.51	0.66	1.31	2.73	1.14	1.35	1.40	1.23
13	200	364	1362	250	333	348	274		13.0	5.5	6.4	6.5	5.8		0.14	1.88	0.33	2.76	2.85		2.63	0.73	1.74	0.60	0.59
8.5	300		1384	285	780	353	287		8.5	3.9	6.4	4.3	3.9		2.10	2.56	0.19	4.21	11.48		0.69	0.63	2.31	0.49	0.30
5	400		1450	328	1395	388	288		5.0	2.4	5.0	2.7	2.3		2.27	3.32	0.24	3.30	64.29		0.66	0.55	2.02	0.55	0.12
3.1	500		1451	339	1396	413	290		3.1	1.5	3.1	1.7	1.4		46.15	6.51	46.15	5.99	17.86		0.15	0.39	0.15	0.41	0.24
1.9	600		1454	358	1399	414	298		1.9	1.0	1.9	1.0	0.9		33.33	5.55	39.47	100.00	15.12		0.17	0.42	0.16	0.10	0.26
---	700		1457	375	1401	415	303	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---

$k \cdot \rho \cdot c$	T,ig (K)	q",crit	h	b	t* (sec)	q"s,min	Ts,min (K)
1.980	548	8.4	0.034	0.027	1372	1.2	345

Slope (Auto) = ---

Slope (Manual)	Φ -- kW²/m³
-1.2	1.2
-0.08	273.0



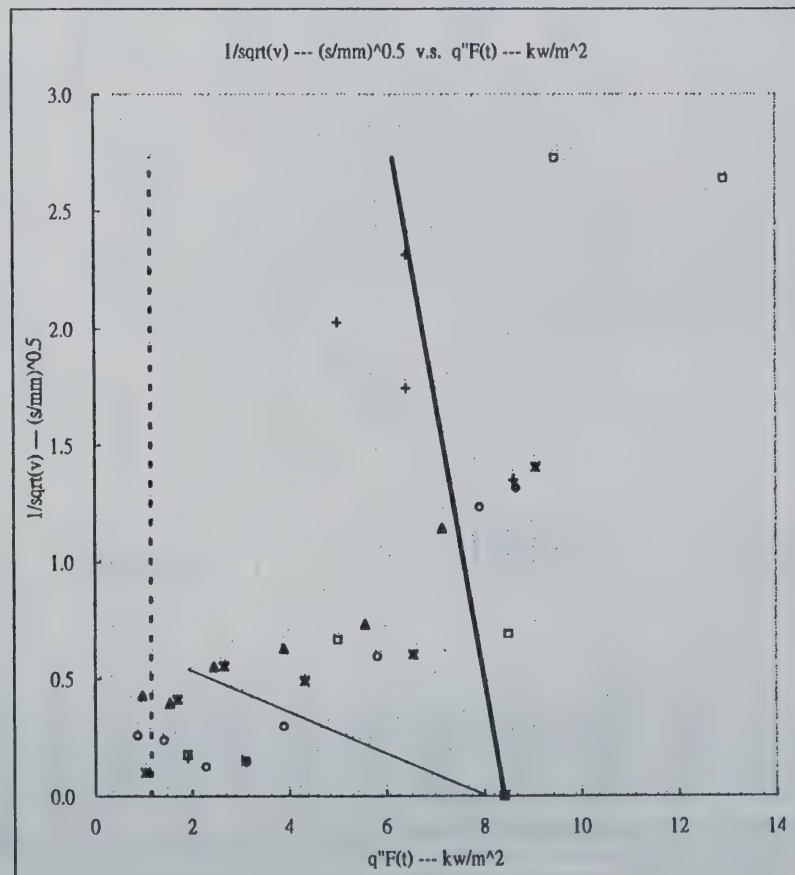


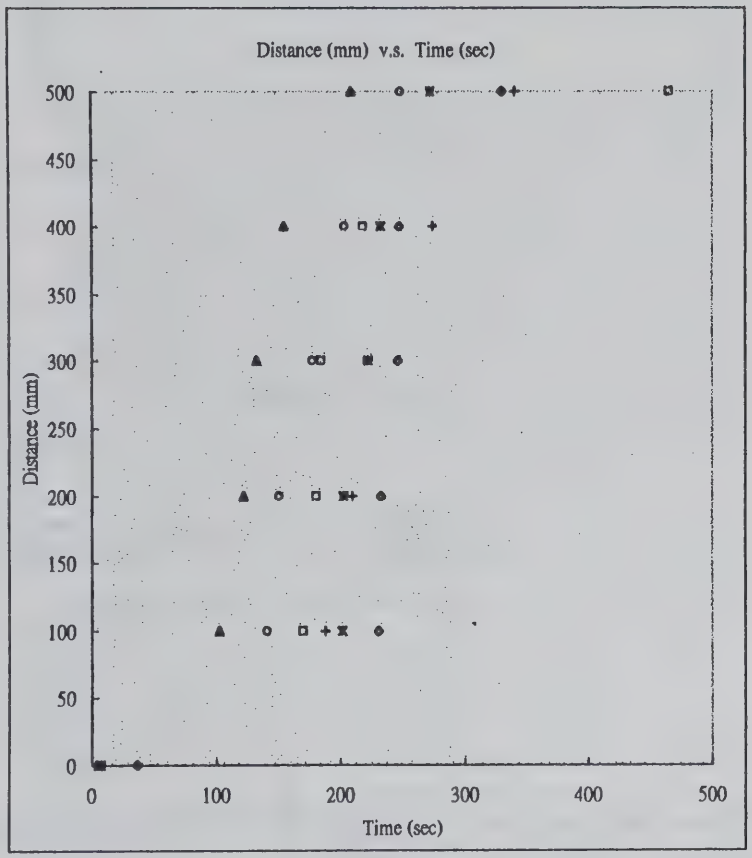
Table - 5 Roland 5-05 (XPS 40mm) Downward Flame Spread

q" (kw/m^2)	Dis.(mm)	#1 (sec)	#2	#3	#4	#5	#6	q" F_1(t)	q" F_2(t)	q" F_3(t)	q" F_4(t)	q" F_5(t)	q" F_6(t)	V_1	V_2	V_3	V_4	V_5	V_6	1/sqrt(V_1)	1/sqrt(V_2)	1/sqrt(V_3)	1/sqrt(V_4)	1/sqrt(V_5)	1/sqrt(V_6)
31.0	0	37	6	5	7	7	5	5.1	2.0	1.9	2.2	2.2	1.9	---	---	---	---	---	---	---	---	---	---	---	---
40.1	100	231	170	103	188	202	141	16.5	14.1	11.0	14.8	15.4	12.9	0.8	0.9	1.5	0.8	0.8	1.1	1.14	1.05	0.82	1.11	1.14	0.95
37.2	200	233	181	122	210	203	151	15.3	13.5	11.1	14.6	14.3	12.3	10.5	12.4	6.5	5.6	7.5	5.1	0.31	0.28	0.39	0.42	0.37	0.44
23.2	300	247	185	133	223	223	178	9.8	8.5	7.2	9.4	9.4	8.4	10.7	4.4	5.8	2.7	6.4	3.8	0.31	0.48	0.41	0.60	0.39	0.51
9.3	400	248	219	155	275	233	204	4.0	3.7	3.1	4.2	3.8	3.6	1.8	0.6	2.5	1.7	3.6	2.8	0.74	1.29	0.63	0.77	0.53	0.60
---	500	331	465	209	341	273	249	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---

$k \cdot \rho \cdot c$	T,ig (K)	q",crit	h	b	t* (sec)	q"s,min	Ts,min (K)
1.980	548	8.4	0.034	0.027	1372	1.2	345

Slope (Auto) = 0.05

Slope (Manual)	Φ -- kw^2/m^3
-0.23	33.0



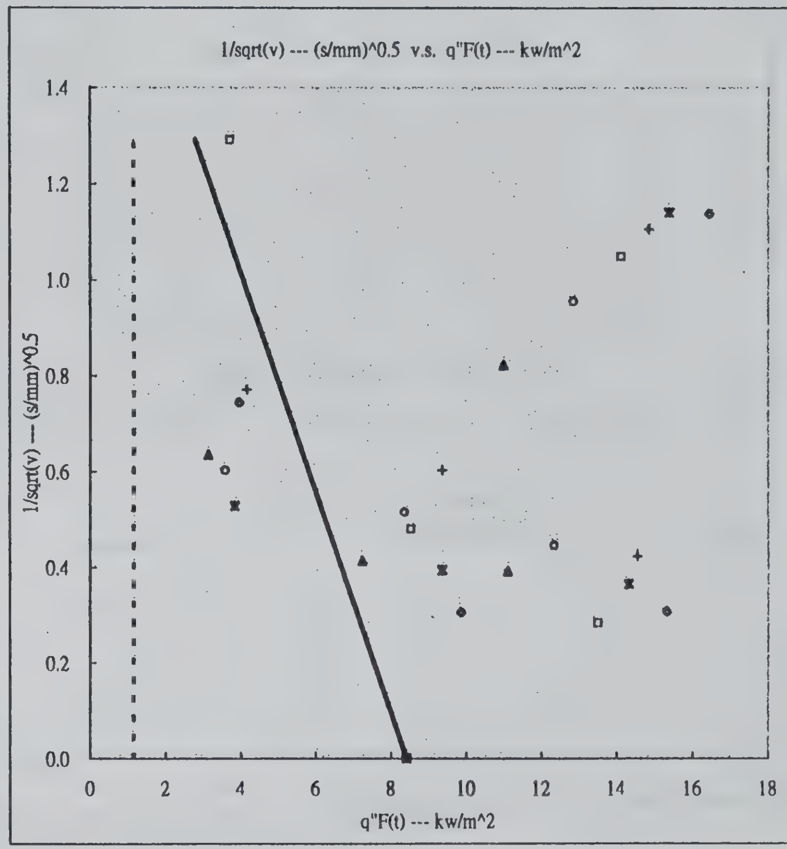
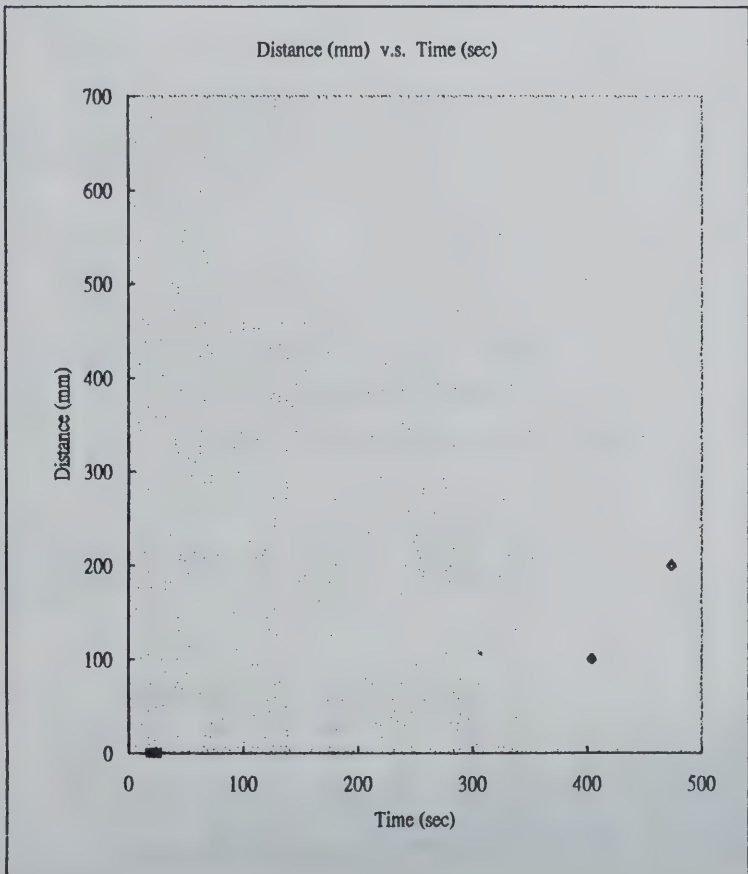


Table - 6 Roland 5-07 (PVC) Lateral Flame Spread

q" (kw/m^2)	Dis.(mm)	#1 (sec)	#2	#3	#4	#5	#6	q" F1(t)	q" F2(t)	q" F3(t)	q" F4(t)	q" F5(t)	q" F6(t)	V1	V2	V3	V4	V5	V6	1/sqrt(V1)	1/sqrt(V2)	1/sqrt(V3)	1/sqrt(V4)	1/sqrt(V5)	1/sqrt(V6)
24.3	0	23	19	23	28	22	22	5.3	4.8	5.3	5.9	5.2	5.2	---	---	---	---	---	---	---	---	---	---	---	---
19.6	100	404						18.0						0.38						1.62					
13	200	474																							
8.5	300																								
5	400																								
3.1	500																								
1.9	600																								
---	700							---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---

$k \cdot \rho \cdot c$	T,ig (K)	q",crit	h	b	t* (sec)	q"s,min	Ts,min (K)	Slope (Auto) =	Slope (Manual)	Φ kw²/m³
1.310	688	18.1	0.046	0.046	477	13.0	622	---	-2	0.2



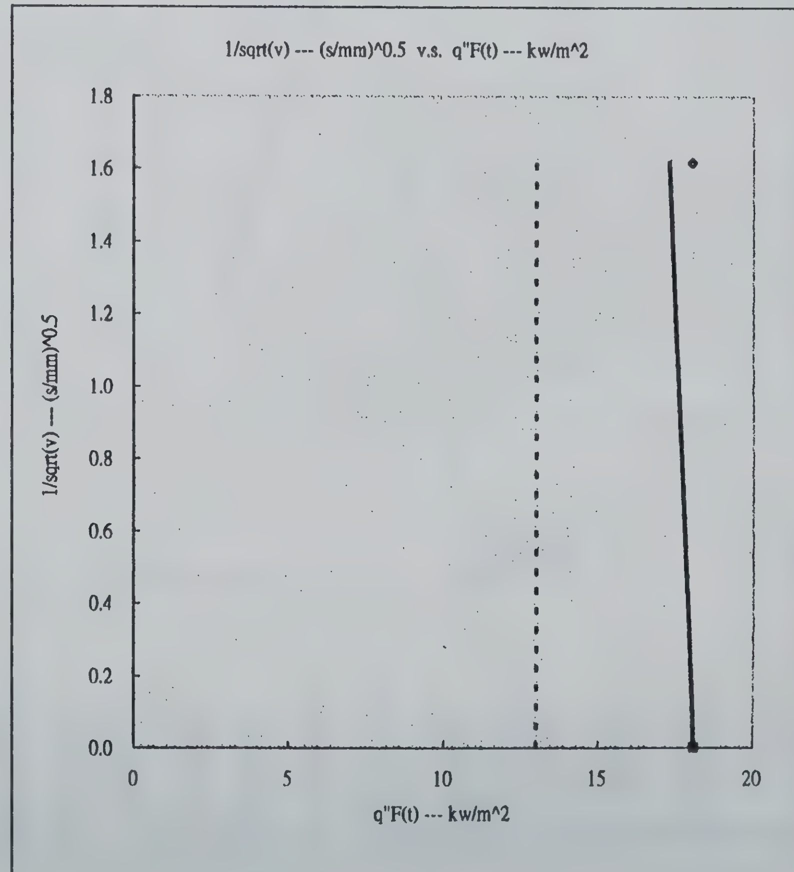
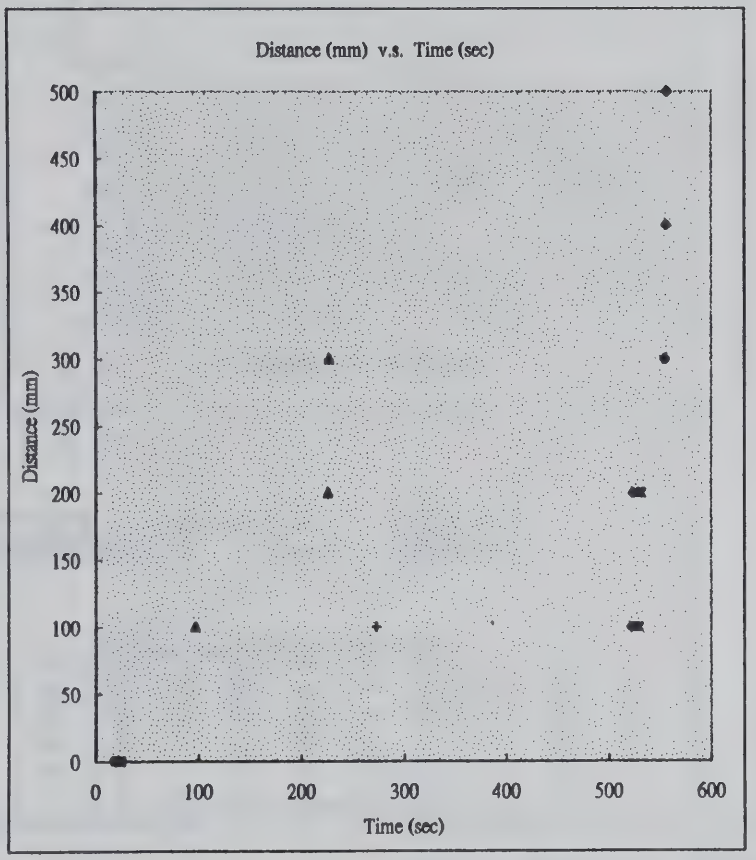


Table - 7 Roland 5-07 (PVC) Downward Flame Spread

q" (kw/m^2)	Dis.(mm)	#1 (sec)	#2	#3	#4	#5	#6	q" F1(t)	q" F2(t)	q" F3(t)	q" F4(t)	q" F5(t)	q" F6(t)	V1	V2	V3	V4	V5	V6	1/sqrt(V1)	1/sqrt(V2)	1/sqrt(V3)	1/sqrt(V4)	1/sqrt(V5)	1/sqrt(V6)
31.0	0	23	19	23	28	22	22	6.8	6.2	6.8	7.5	6.7	6.7	---	---	---	---	---	---	---	---	---	---	---	---
40.1	100	522		97	274	529		40.1		18.1		40.1		0.3		1.0		0.3		1.82		1.02		1.84	
37.2	200	524		227		532		37.2		25.7				4.8		1.2				0.46		0.93			
23.2	300	555		228				23.2						4.8						0.45					
9.3	400	556						9.3						100.0						0.10					
---	500	557						---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---

$k \cdot \rho \cdot c$	T,ig (K)	q",crit	h	b	t* (sec)	q"s,min	Ts,min (K)	Slope (Auto) =	Slope (Manual)	Φ—kw²/m³
1.310	688	18.1	0.046	0.046	477	13.0	622	0.07	-0.3	6.8



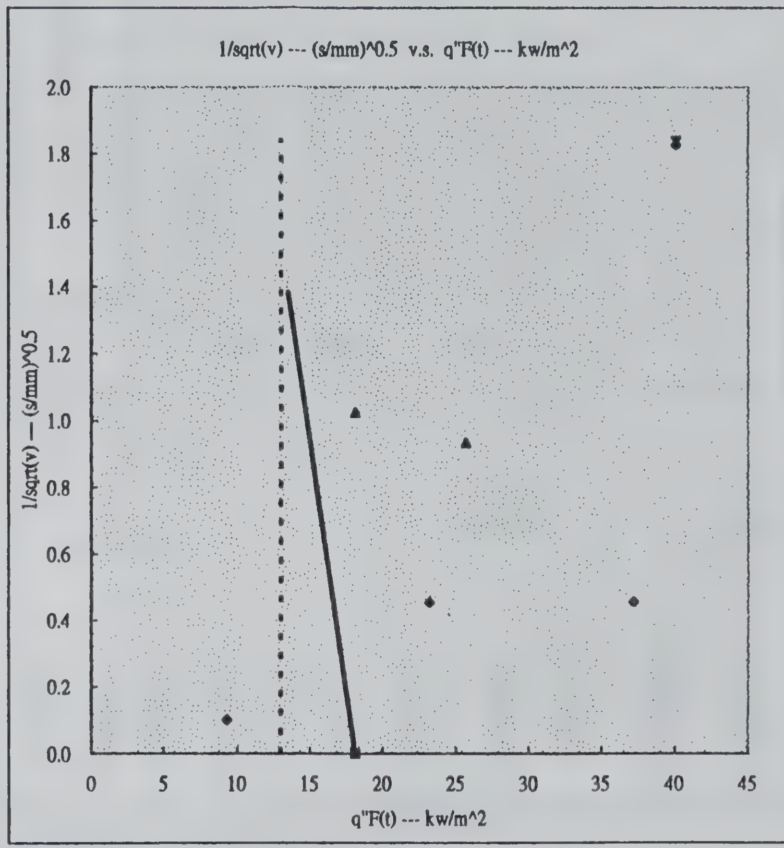


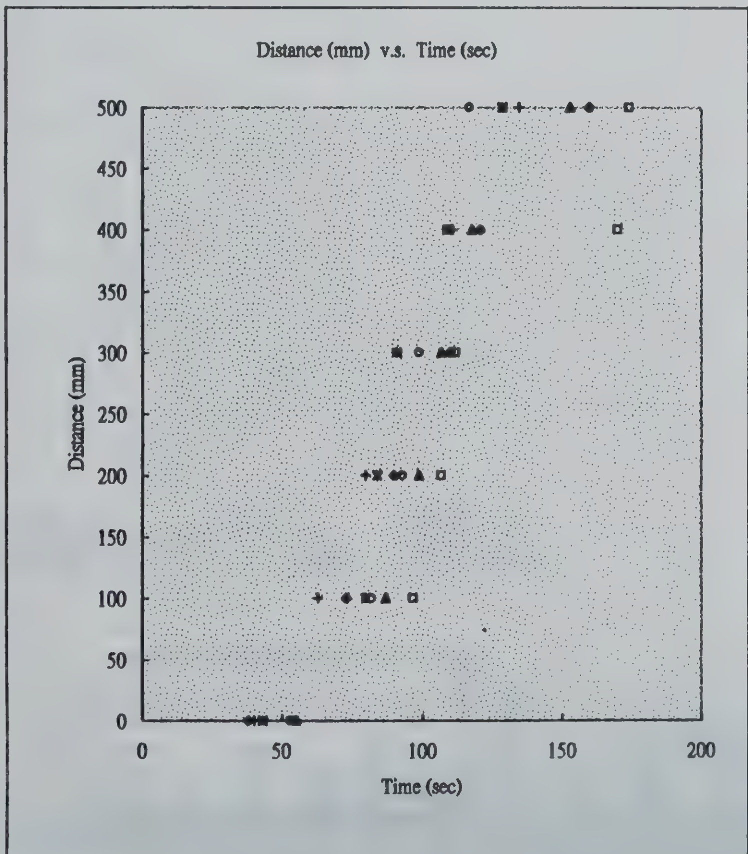
Table - 8 Roland 5-08 (Layered Polycarbonate) Downward Flame Spread

q" (kw/m^2)	Dis.(mm)	#1 (sec)	#2	#3	#4	#5	#6	$q''_{F1}(t)$	$q''_{F2}(t)$	$q''_{F3}(t)$	$q''_{F4}(t)$	$q''_{F5}(t)$	$q''_{F6}(t)$	V_1	V_2	V_3	V_4	V_5	V_6	1/sqrt(V_1)	1/sqrt(V_2)	1/sqrt(V_3)	1/sqrt(V_4)	1/sqrt(V_5)	1/sqrt(V_6)
31.0	0	38	54	55	40	43	53	10.0	11.9	12.0	10.2	10.6	11.8	---	---	---	---	---	---	---	---	---	---	---	---
40.1	100	73	97	87	63	80	82	17.9	20.6	19.5	16.6	18.7	18.9	3.7	3.3	4.3	5.0	4.0	4.7	0.52	0.55	0.48	0.45	0.50	0.46
37.2	200	90	107	99	80	84	93	18.4	20.1	19.3	17.3	17.8	18.7	5.4	12.9	9.9	7.0	17.7	11.4	0.43	0.28	0.32	0.38	0.24	0.30
23.2	300	110	112	107	91	91	99	12.7	12.8	12.5	11.5	11.5	12.0	6.3	2.6	10.4	6.3	7.5	12.2	0.40	0.62	0.31	0.40	0.36	0.29
9.3	400	121	170	118	111	109	109	5.3	6.3	5.3	5.1	5.1	5.1	3.6	2.6	4.0	4.5	5.3	11.1	0.53	0.62	0.50	0.47	0.44	0.30
---	500	160	174	153	135	129	117	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---

$k \cdot \rho \cdot c$	T,ig (K)	q",crit	h	b	t* (sec)	q"s,min	Ts,min (K)
1.470	768	26.3	0.056	0.052	368	3.7	435

Slope (Auto) = -0.03

Slope (Manual)	Φ — kw²/m³
-0.03	520.5



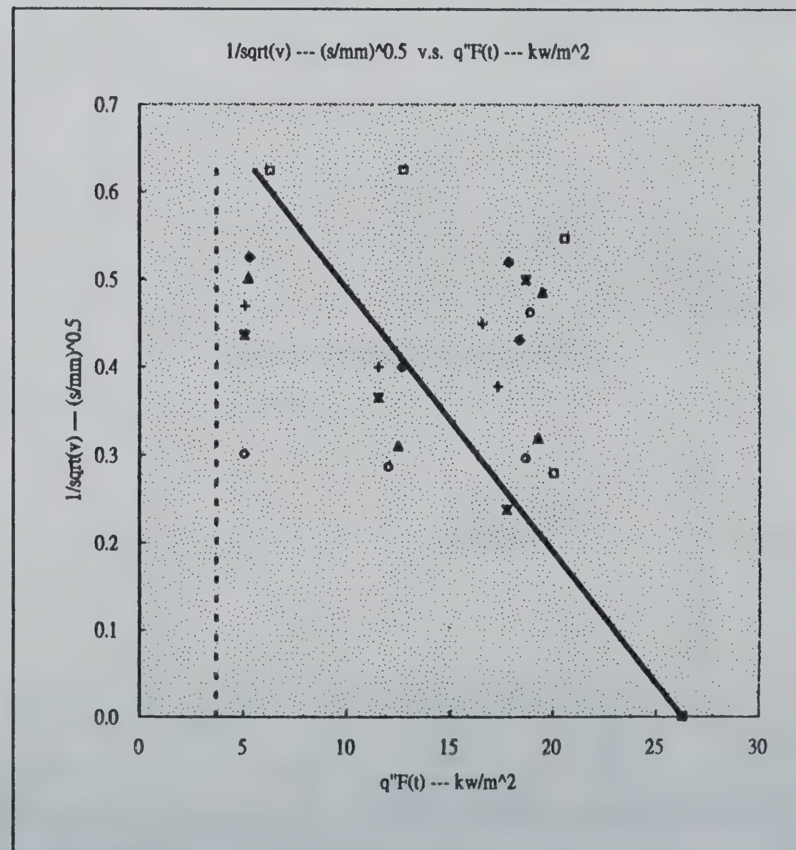


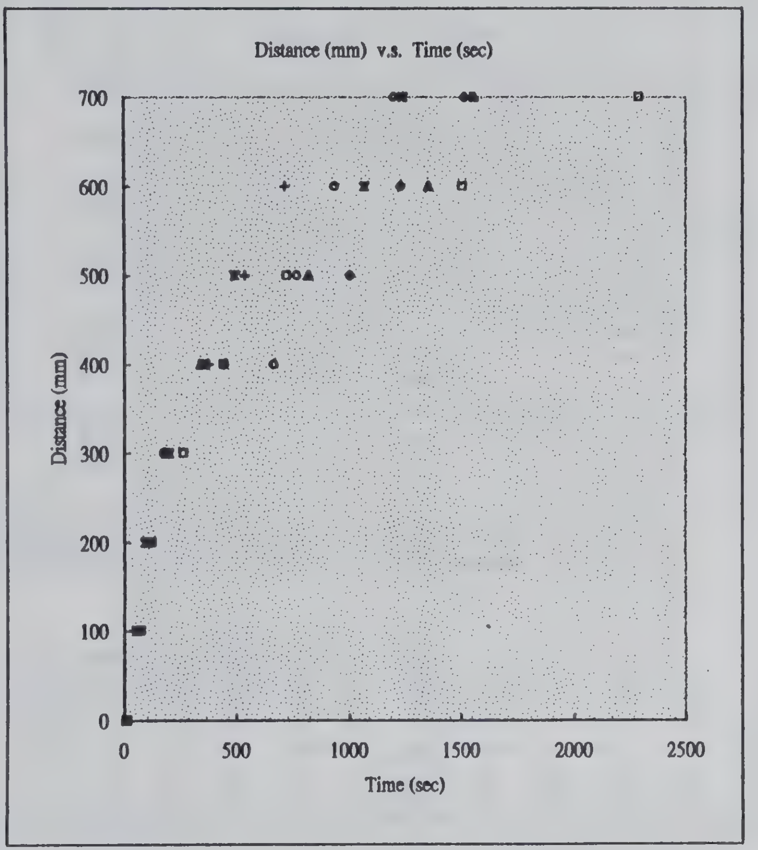
Table - 9 Roland 5-09 (Massive Timber Varnished) Lateral Flame Spread

q" (kw/m^2)	Dis.(mm)	#1 (sec)	#2	#3	#4	#5	#6	q" F_1(t)	q" F_2(t)	q" F_3(t)	q" F_4(t)	q" F_5(t)	q" F_6(t)	V_1	V_2	V_3	V_4	V_5	V_6	1/sqrt(V_1)	1/sqrt(V_2)	1/sqrt(V_3)	1/sqrt(V_4)	1/sqrt(V_5)	1/sqrt(V_6)
24.3	0	8	10	8	10	12	17	4.1	4.5	4.1	4.5	5.0	5.9	---	---	---	---	---	---	---	---	---	---	---	---
19.6	100	64	76	59	68	55	57	9.3	10.1	8.9	9.5	8.6	8.7	1.94	1.73	2.12	2.02	2.47	2.19	0.72	0.76	0.69	0.70	0.64	0.68
13	200	111	125	102	108	93	108	8.1	8.6	7.8	8.0	7.4	8.0	1.49	0.99	1.43	1.56	1.27	1.65	0.82	1.01	0.84	0.80	0.89	0.78
8.5	300	195	264	193	191	201	177	7.0	8.2	7.0	6.9	7.1	6.7	0.56	0.62	0.82	0.71	0.76	0.30	1.34	1.27	1.11	1.19	1.15	1.82
5	400	444	445	342	377	353	668	5.0	5.0	5.0	5.0	5.0	5.0	0.24	0.43	0.29	0.58	0.68	0.30	2.06	1.53	1.85	1.32	1.21	1.84
3.1	500	1005	723	821	538	493	769	3.1	3.1	3.1	3.1	3.1	3.1	0.24	0.18	0.20	0.59	0.25	0.73	2.04	2.39	2.25	1.30	2.01	1.17
1.9	600	1231	1507	1356	717	1070	938	1.9	1.9	1.9	1.9	1.9	1.9	0.39	0.13	0.25	0.17	0.24	0.45	1.60	2.80	1.99	2.39	2.03	1.49
---	700	1516	2292	1560	1544	1242	1204	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---

$k \cdot \rho \cdot c$	T,ig (K)	q",crit	h	b	t* (sec)	q"s,min	Ts,min (K)
0.530	603	11.6	0.038	0.059	287	1.2	345

Slope (Auto) = -0.23

Slope (Manual)	Φ -- kw^2/m^3
-0.23	6.9



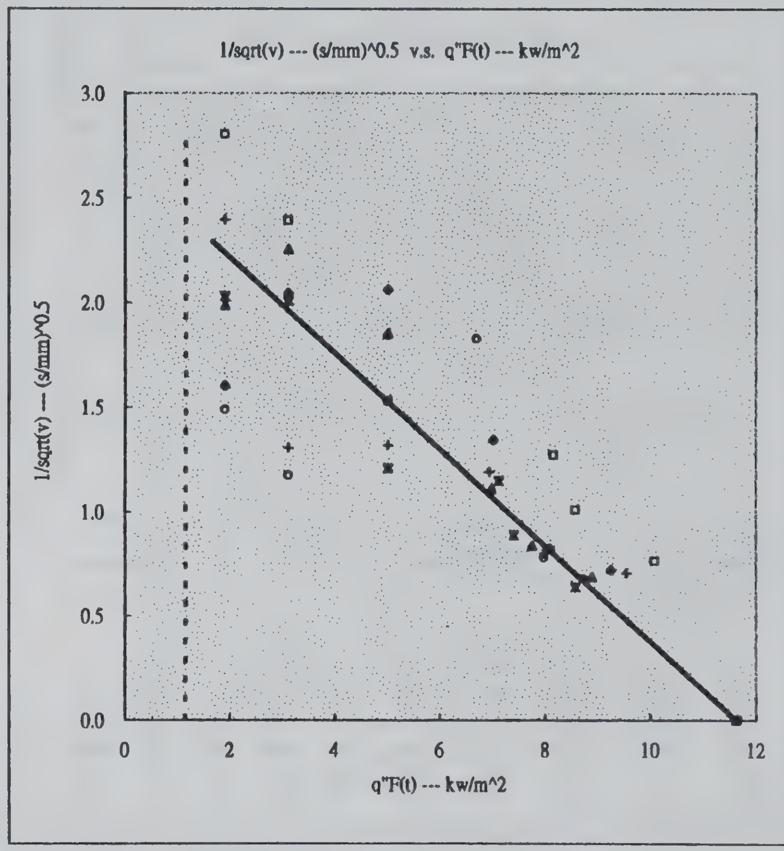


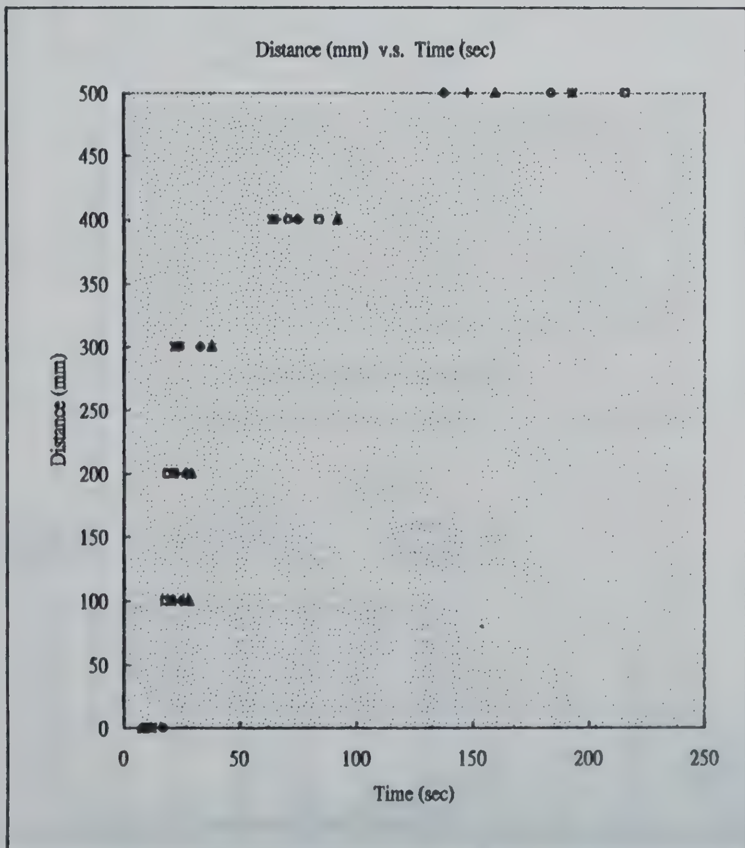
Table - 10 Roland 5-09 (Massive Timber Varnished) Downward Flame Spread

q" (kw/m^2)	Dis.(mm)	#1 (sec)	#2	#3	#4	#5	#6	q" F1(t)	q" F2(t)	q" F3(t)	q" F4(t)	q" F5(t)	q" F6(t)	V1	V2	V3	V4	V5	V6	1/sqrt(V1)	1/sqrt(V2)	1/sqrt(V3)	1/sqrt(V4)	1/sqrt(V5)	1/sqrt(V6)
31.0	0	8	10	8	10	12	17	5.2	5.8	5.2	5.8	6.3	7.5	---	---	---	---	---	---	---	---	---	---	---	---
40.1	100	25	18	28	22	20	21	11.8	10.0	12.5	11.1	10.6	10.9	8.7	18.5	7.5	12.4	18.5	35.7	0.34	0.23	0.37	0.28	0.23	0.17
37.2	200	27	19	29	23	21	22	11.4	9.6	11.8	10.5	10.1	10.3	23.1	29.0	16.5	100.0	100.0	100.0	0.21	0.19	0.25	0.10	0.10	0.10
23.2	300	33	24	38	24	22	23	7.9	6.7	8.4	6.7	6.4	6.6	3.5	2.5	2.7	3.6	3.6	3.1	0.53	0.63	0.61	0.53	0.53	0.57
9.3	400	75	84	92	66	64	71	4.8	5.0	5.3	4.5	4.4	4.6	1.9	1.0	1.6	1.6	1.1	1.2	0.73	1.00	0.78	0.80	0.96	0.92
---	500	138	216	160	148	193	184	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---

$k \cdot \rho \cdot c$	T,ig (K)	q",crit	h	b	t* (sec)	q"s,min	Ts,min (K)
0.530	603	11.6	0.038	0.059	287	1.2	345

Slope (Auto) = -0.12

Slope (Manual)	Φ -- kw²/m³
-0.12	25.3



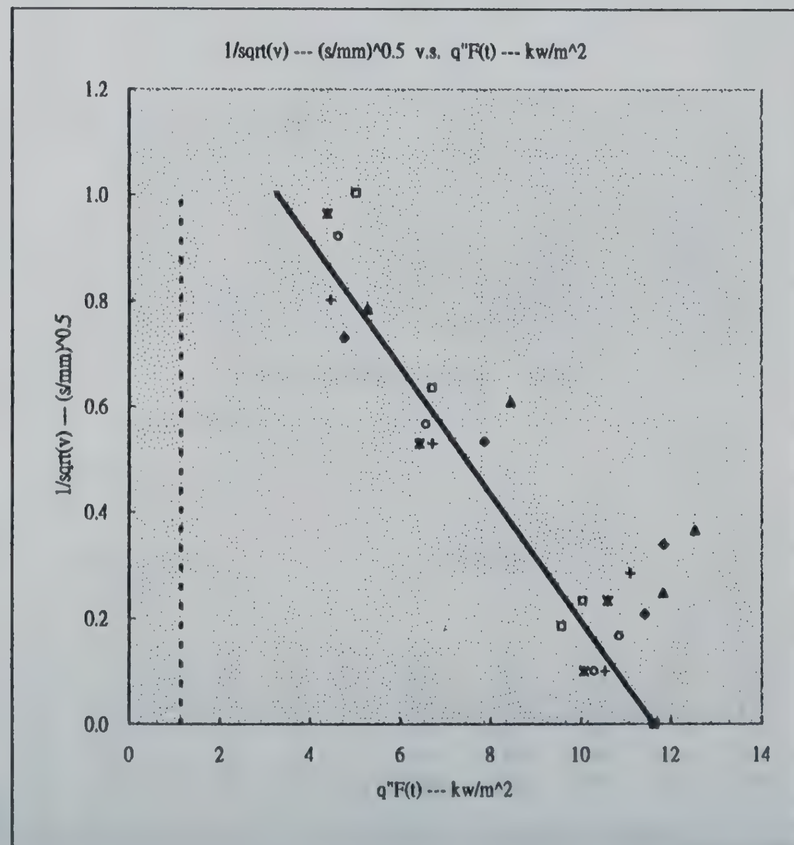


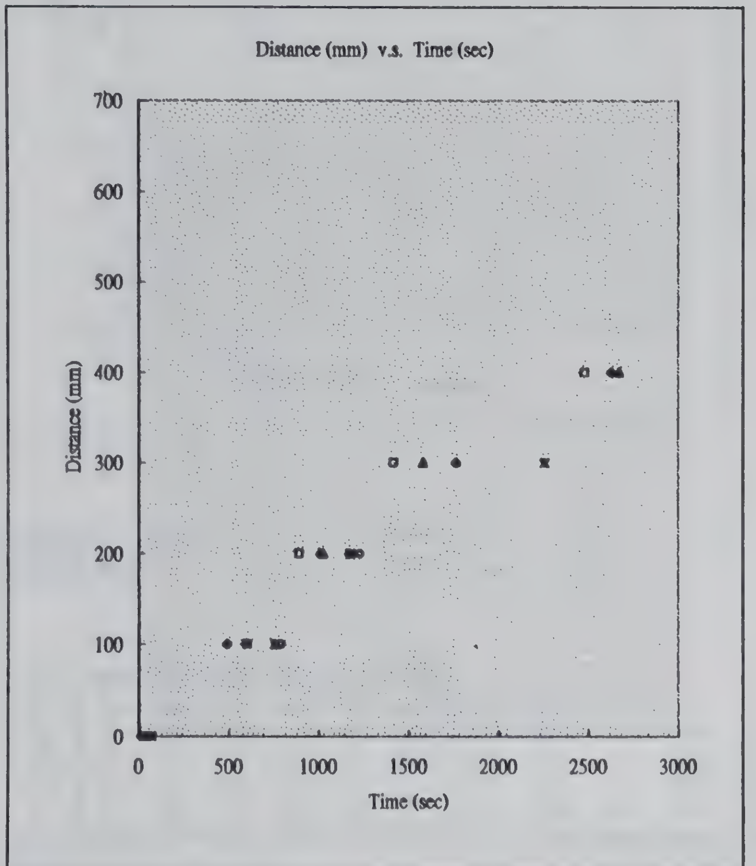
Table - 11 Roland 5-10 (FR Plywood) Lateral Flame Spread

q" (kw/m^2)	Dis.(mm)	#1 (sec)	#2	#3	#4	#5	#6	q" F_1(t)	q" F_2(t)	q" F_3(t)	q" F_4(t)	q" F_5(t)	q" F_6(t)	V_1	V_2	V_3	V_4	V_5	V_6	1/sqrt(V_1)	1/sqrt(V_2)	1/sqrt(V_3)	1/sqrt(V_4)	1/sqrt(V_5)	1/sqrt(V_6)
24.3	0	15	38	28	55	70	62	17.6	24.3	24.1	24.3	24.3	24.3	---	---	---	---	---	---	---	---	---	---	---	---
19.6	100	494	604	761	593	760	793	19.6	19.6	19.6	19.6	19.6	19.6	0.20	0.23	0.19	0.18	0.18	0.17	2.23	2.10	2.31	2.36	2.38	2.45
13	200	1013	893	1027	1171	1178	1234	13.0	13.0	13.0		13.0		0.16	0.24	0.23		0.13		2.54	2.05	2.07		2.83	
8.5	300	1766	1424	1583		2260		8.5	8.5	8.5				0.12	0.12	0.12				2.85	2.87	2.92			
5	400	2630	2481	2673																					
3.1	500																								
1.9	600																								
---	700							---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---

$k \cdot \rho \cdot c$	T,ig (K)	q",crit	h	b	t* (sec)	q"s,min	Ts,min (K)
0.106	753	24.6	0.054	0.187	28	5.0	470

Slope (Auto) = -0.22

Slope (Manual)	Φ — kw^2/m^3
-0.22	0.7



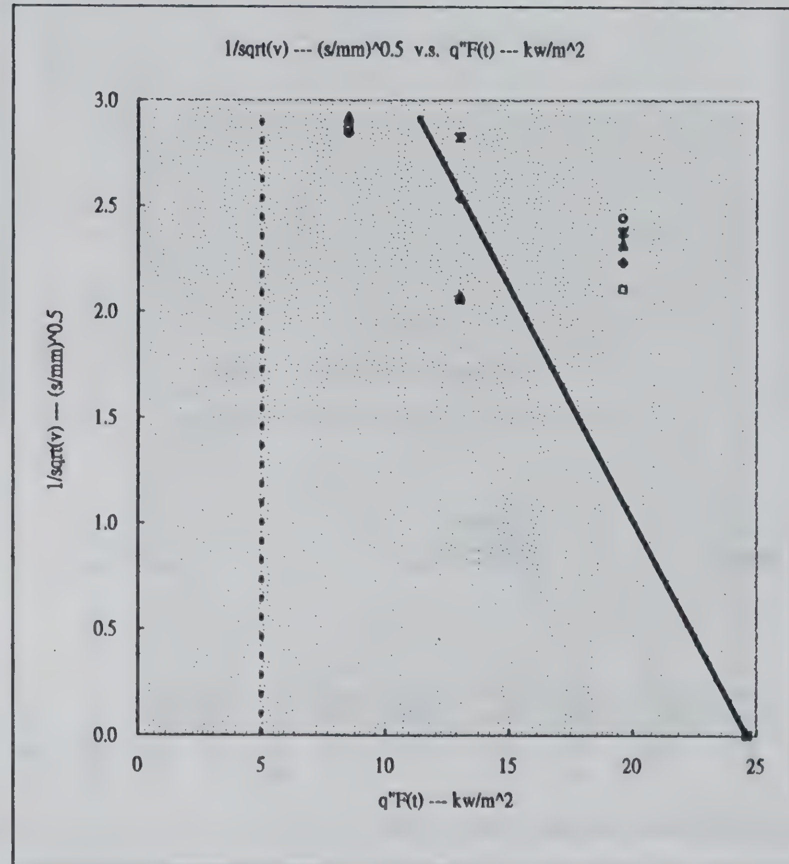


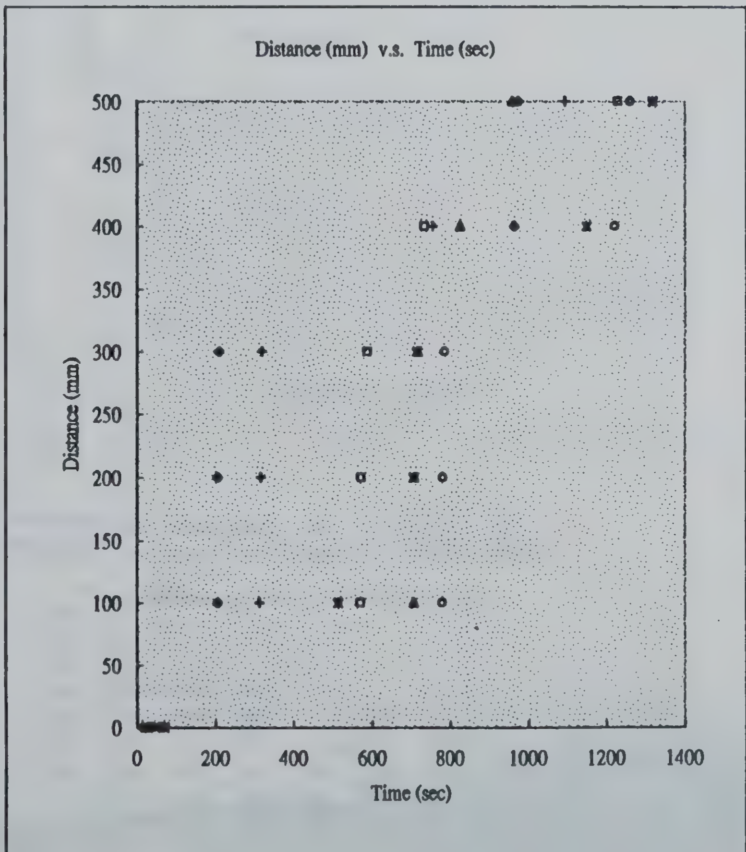
Table - 12 Roland 5-10 (FR Plywood) Downward Flame Spread

q" (kw/m^2)	Dis.(mm)	#1 (sec)	#2	#3	#4	#5	#6	q" F1(t)	q" F2(t)	q" F3(t)	q" F4(t)	q" F5(t)	q" F6(t)	V_1	V_2	V_3	V_4	V_5	V_6	1/sqrt(V1)	1/sqrt(V2)	1/sqrt(V3)	1/sqrt(V4)	1/sqrt(V5)	1/sqrt(V6)
31.0	0	15	38	28	56	70	62	22.5	31.0	30.7	31.0	31.0	31.0	---	---	---	---	---	---	---	---	---	---	---	---
40.1	100	207	571	707	314	514	780	40.1	40.1	40.1	40.1	40.1	40.1	0.8	0.3	0.2	0.6	0.3	0.2	1.13	1.89	2.13	1.31	1.83	2.19
37.2	200	208	572	708	316	706	782	37.2	37.2	37.2	37.2	37.2	37.2	64.3	8.8	16.5	32.1	0.8	32.1	0.12	0.34	0.25	0.18	1.13	0.18
23.2	300	210	589	717	320	714	786	23.2	23.2	23.2	23.2	23.2	23.2	0.2	1.0	1.4	0.3	0.3	0.3	2.24	0.99	0.85	1.70	1.70	1.70
9.3	400	964	734	825	756	1149	1220	9.3	9.3	9.3	9.3	9.3	9.3	0.2	0.3	0.8	0.3	0.3	0.3	2.24	1.88	1.10	1.97	1.79	1.71
---	500	974	1229	960	1093	1316	1259	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---

$k \cdot \rho \cdot c$	T,ig (K)	q",crit	h	b	t* (sec)	q"s,min	Ts,min (K)
0.106	753	24.6	0.054	0.187	28	1.2	345

Slope (Auto) = ---

Slope (Manual)	Φ -- kw^2/m^3
-0.18	1.1



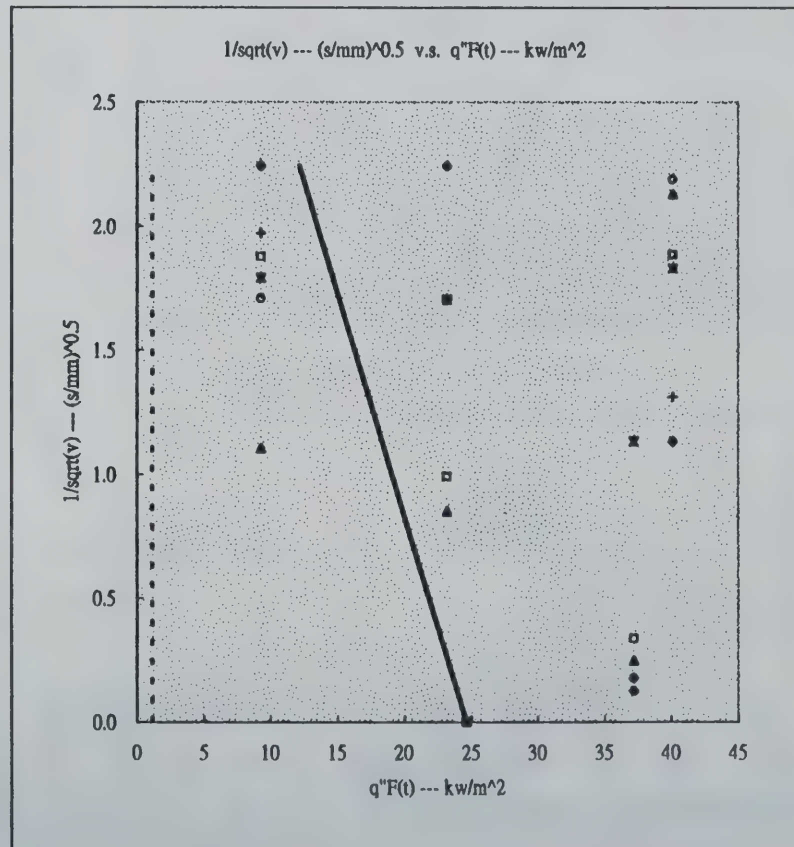
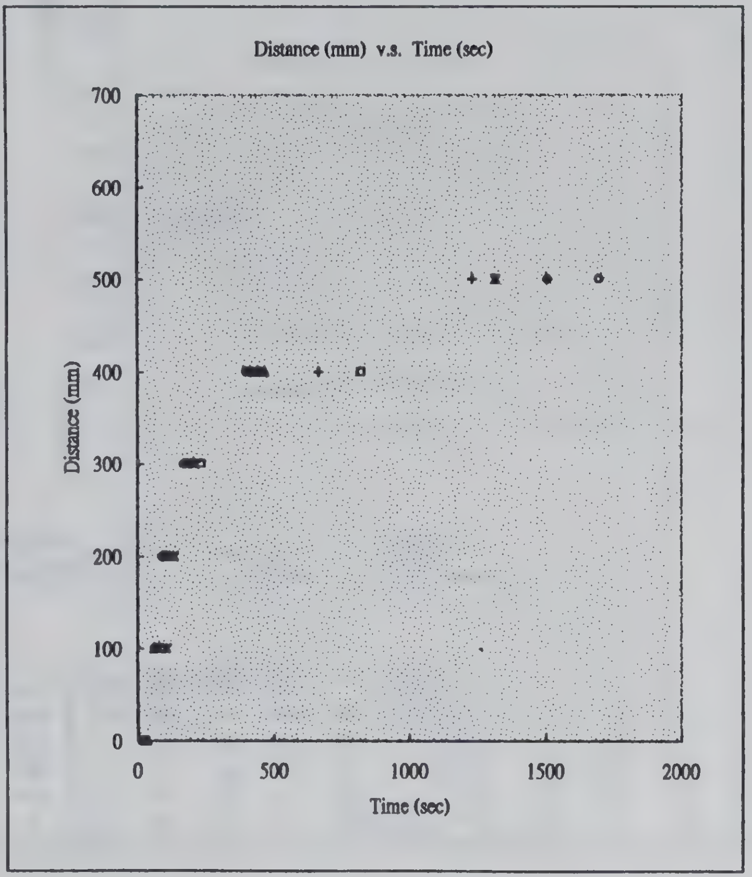


Table - 13 Roland 5-11 (Standard Plywood) Lateral Flame Spread

q" (kw/m^2)	Dis.(mm)	#1 (sec)	#2	#3	#4	#5	#6	q" F1(t)	q" F2(t)	q" F3(t)	q" F4(t)	q" F5(t)	q" F6(t)	V_1	V_2	V_3	V_4	V_5	V_6	1/sqrt(V_1)	1/sqrt(V_2)	1/sqrt(V_3)	1/sqrt(V_4)	1/sqrt(V_5)	1/sqrt(V_6)
24.3	0	27	19	32	29	25	18	6.2	5.2	6.8	6.5	6.0	5.1	---	---	---	---	---	---	---	---	---	---	---	---
19.6	100	69	74	64	71	107	65	8.0	8.3	7.7	8.1	10.0	7.8	2.92	2.11	2.57	2.56	1.67	2.17	0.58	0.69	0.62	0.63	0.77	0.68
13	200	94	113	109	107	136	110	6.2	6.8	6.7	6.6	7.5	6.7	1.76	1.13	1.59	1.55	1.73	1.70	0.75	0.94	0.79	0.80	0.76	0.77
8.5	300	173	236	187	193	215	181	5.5	6.4	5.7	5.8	6.1	5.6	0.57	0.25	0.50	0.31	0.61	0.62	1.32	2.02	1.41	1.80	1.28	1.27
5	400	417	826	468	668	441	404	5.0			5.0	5.0	5.0	0.13			0.19	0.16	0.11	2.75			2.28	2.48	2.97
3.1	500	1507			1233	1317	1697																		
1.9	600																								
---	700							---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---

$k \cdot \rho \cdot c$	T,ig (K)	q",crit	h	b	t* (sec)	q"s,min	Ts,min (K)	Slope (Auto) =	Slope (Manual)	Φ --- kw^2/m^3
0.634	563	9.2	0.035	0.049	411	3.1	415	-0.49	-0.49	2.2



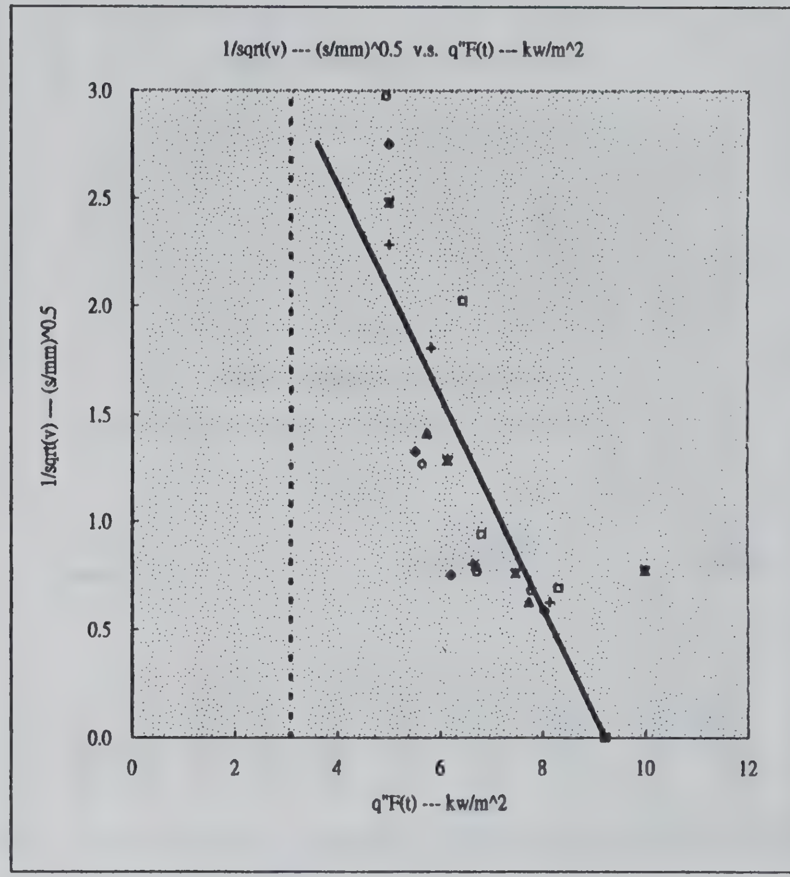
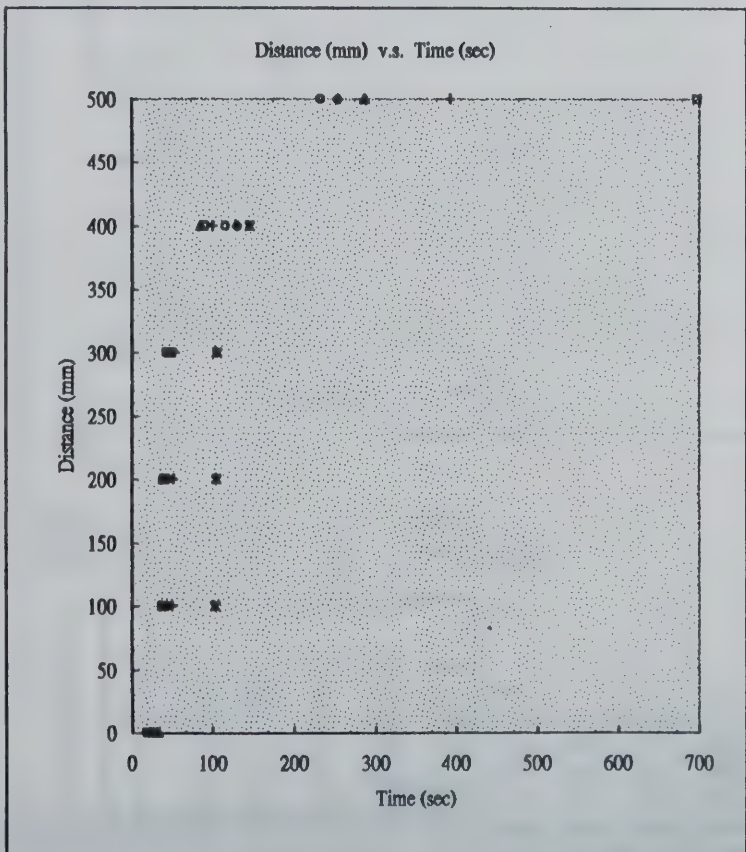


Table - 14 Roland 5-11 (Standard Plywood) Downward Flame Spread

q" (kw/m^2)	Dis.(mm)	#1 (sec)	#2	#3	#4	#5	#6	q" F_1(t)	q" F_2(t)	q" F_3(t)	q" F_4(t)	q" F_5(t)	q" F_6(t)	V_1	V_2	V_3	V_4	V_5	V_6	1/sqrt(V_1)	1/sqrt(V_2)	1/sqrt(V_3)	1/sqrt(V_4)	1/sqrt(V_5)	1/sqrt(V_6)
31.0	0	27	19	32	29	25	18	7.9	6.7	8.7	8.2	7.6	6.5	---	---	---	---	---	---	---	---	---	---	---	---
40.1	100	43	39	38	50	103	37	13.0	12.4	12.2	14.0	20.1	12.0	9.3	7.5	24.4	7.1	1.9	7.8	0.33	0.37	0.20	0.37	0.72	0.36
37.2	200	44	40	39	51	105	39	12.2	11.6	11.5	13.1	18.8	11.5	64.3	46.2	16.5	64.3	64.3	13.3	0.12	0.15	0.25	0.12	0.12	0.27
23.2	300	46	43	48	53	106	50	7.8	7.5	7.9	8.3	11.8	8.1	1.8	3.2	3.9	3.2	3.7	2.2	0.75	0.56	0.51	0.56	0.52	0.67
9.3	400	130	90	85	100	146	116	5.2	4.4	4.2	4.6		4.9	0.9	0.2	0.7	0.5		1.1	1.03	2.02	1.18	1.41		0.97
---	500	255	698	288	393		233	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---

$k \cdot \rho \cdot c$	T,ig (K)	q",crit	h	b	t* (sec)	q"s,min	Ts,min (K)	Slope (Auto) =	Slope (Manual)	Φ — kw²/m³
0.634	563	9.2	0.035	0.049	411	3.1	415	---	-0.38	3.6



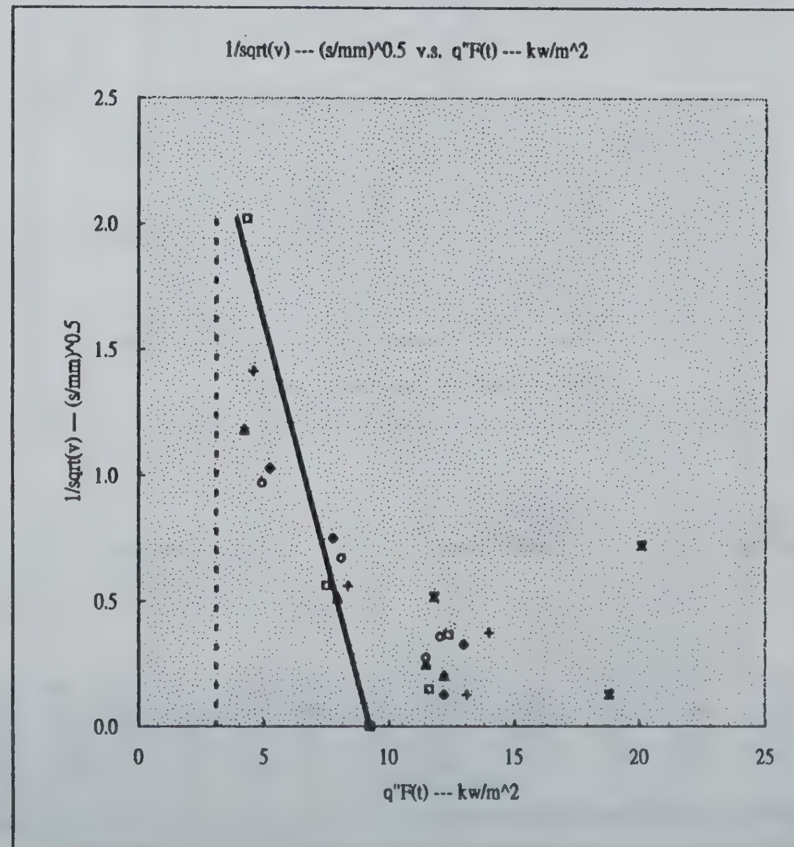


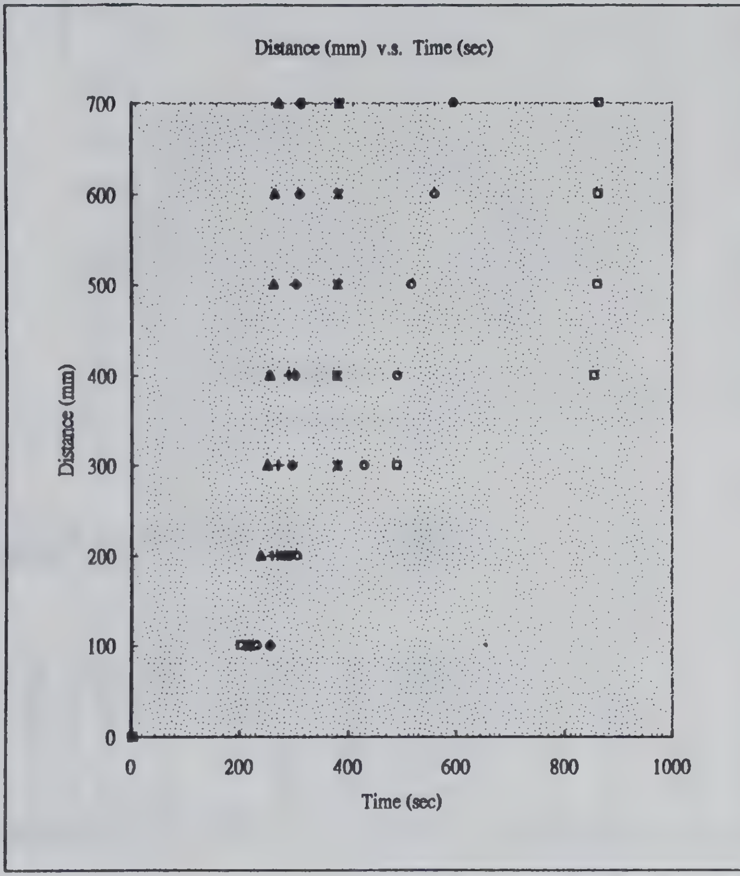
Table - 15 Roland 5-12 (FR EPS 40mm) Lateral Flame Spread

q" (kw/m^2)	Dis.(mm)	#1 (sec)	#2	#3	#4	#5	#6	q" F1(t)	q" F2(t)	q" F3(t)	q" F4(t)	q" F5(t)	q" F6(t)	V1	V2	V3	V4	V5	V6	1/sqrt(V1)	1/sqrt(V2)	1/sqrt(V3)	1/sqrt(V4)	1/sqrt(V5)	1/sqrt(V6)
24.3	0	2	2	4	4	2	4	1.1	1.1	1.5	1.5	1.1	1.5	---	---	---	---	---	---	---	---	---	---	---	---
19.6	100	257	203	220	217	215	232	9.9	8.8	9.2	9.1	9.1	9.4	0.58	0.65	0.69	0.68	0.66	0.61	1.31	1.24	1.20	1.21	1.23	1.28
13	200	292	296	240	261	277	307	7.0	7.0	6.3	6.6	6.8	7.2	4.18	0.66	6.12	3.25	1.18	0.98	0.49	1.23	0.40	0.55	0.92	1.01
8.5	300	298	492	252	272	381	432	4.6	5.9	4.3	4.4	5.2	5.6	16.67	0.35	11.14	6.28	1.44	1.03	0.24	1.70	0.30	0.40	0.83	0.98
5	400	304	857	257	292	382	493	2.7	4.6	2.5	2.7	3.1	3.5	23.08	0.41	16.51	6.12	100.00	2.18	0.21	1.56	0.25	0.40	0.10	0.68
3.1	500	306	863	264	304	383	519	1.7	2.9	1.6	1.7	1.9	2.2	23.08	24.42	18.99	9.46	100.00	2.84	0.21	0.20	0.23	0.33	0.10	0.59
1.9	600	312	864	267	313	384	562	1.1	1.8	1.0	1.1	1.2	1.4	24.42	100.00	21.43	13.16	100.00	2.59	0.20	0.10	0.22	0.28	0.10	0.62
---	700	313	865	273	319	385	596	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---

$k \cdot \rho \cdot c$	T,ig (K)	q",crit	h	b	t* (sec)	q"s,min	Ts,min (K)
1.590	568	9.5	0.035	0.032	1008	1.2	345

Slope (Auto) = ---

Slope (Manual)	Φ-- kw²/m³
-0.55	4.2
-0.05	513.2



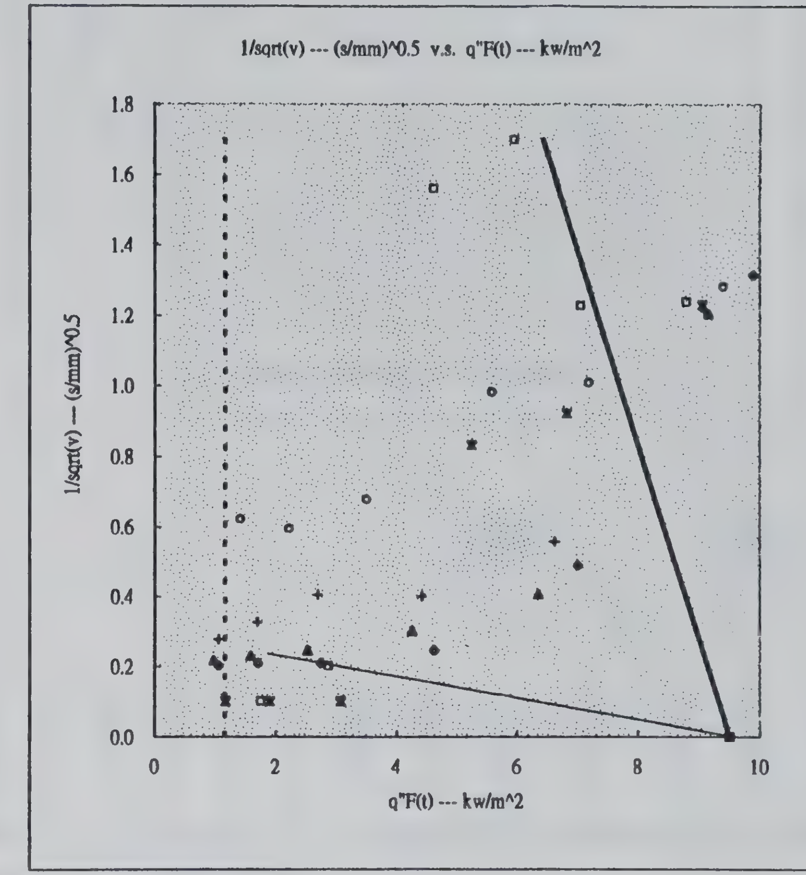
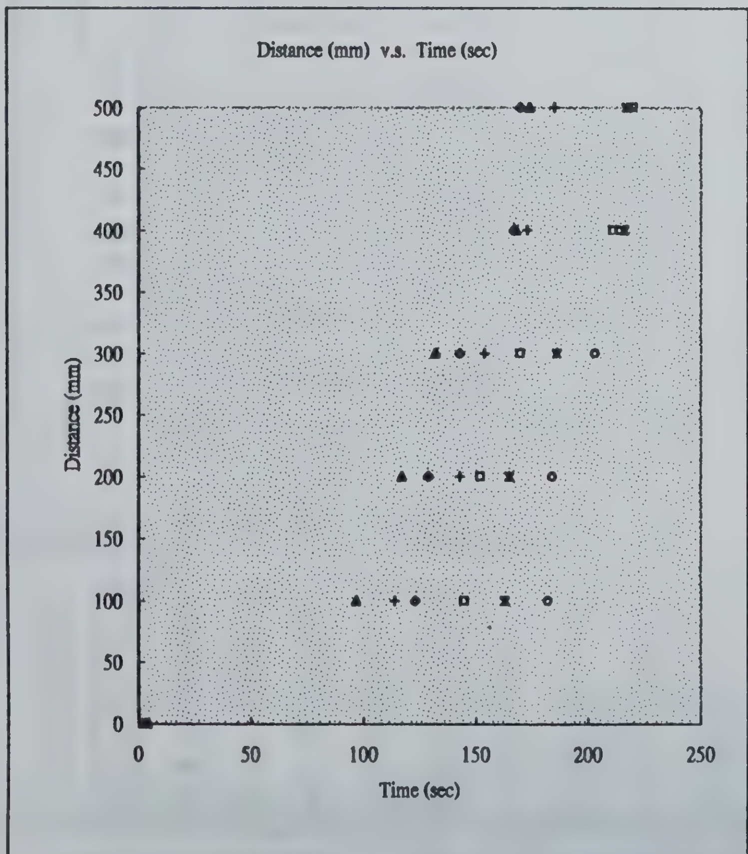


Table - 16 Roland 5-12 (FR EPS 40mm) Downward Flame Spread

q" (kw/m^2)	Dis.(mm)	#1 (sec)	#2	#3	#4	#5	#6	q" F1(t)	q" F2(t)	q" F3(t)	q" F4(t)	q" F5(t)	q" F6(t)	V1	V2	V3	V4	V5	V6	1/sqrt(V1)	1/sqrt(V2)	1/sqrt(V3)	1/sqrt(V4)	1/sqrt(V5)	1/sqrt(V6)
31.0	0	2	2	4	4	2	4	1.4	1.4	2.0	2.0	1.4	2.0	---	---	---	---	---	---	---	---	---	---	---	---
40.1	100	123	145	97	114	163	182	14.0	15.2	12.4	13.5	16.1	17.0	1.2	1.0	1.6	1.3	0.9	0.8	0.90	0.98	0.80	0.88	1.04	1.09
37.2	200	129	152	117	143	165	184	13.3	14.4	12.7	14.0	15.1	15.9	9.5	7.5	5.7	4.7	7.1	7.8	0.32	0.36	0.42	0.46	0.38	0.36
23.2	300	143	170	132	154	186	203	8.7	9.5	8.4	9.1	10.0	10.4	5.1	3.2	3.7	6.5	3.9	6.5	0.44	0.56	0.52	0.39	0.51	0.39
9.3	400	167	211	168	173	216	214	3.8	4.3	3.8	3.9	4.3	4.3	6.2	3.5	4.1	6.3	5.0	12.4	0.40	0.53	0.50	0.40	0.45	0.28
---	500	170	220	174	185	217	218	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---

$k \cdot \rho \cdot c$	T,ig (K)	q",crit	h	b	t* (sec)	q"s,min	Ts,min (K)	Slope (Auto) =	Slope (Manual)	Φ-kw/m
1.590	568	9.5	0.035	0.032	1008	1.2	345	---	-0.08	200.5



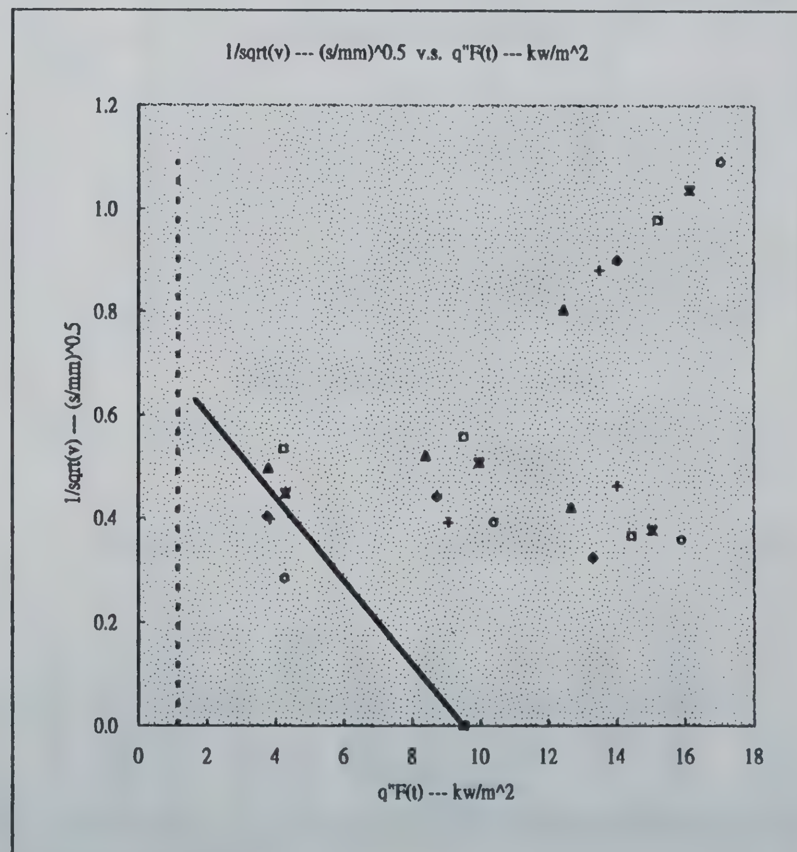


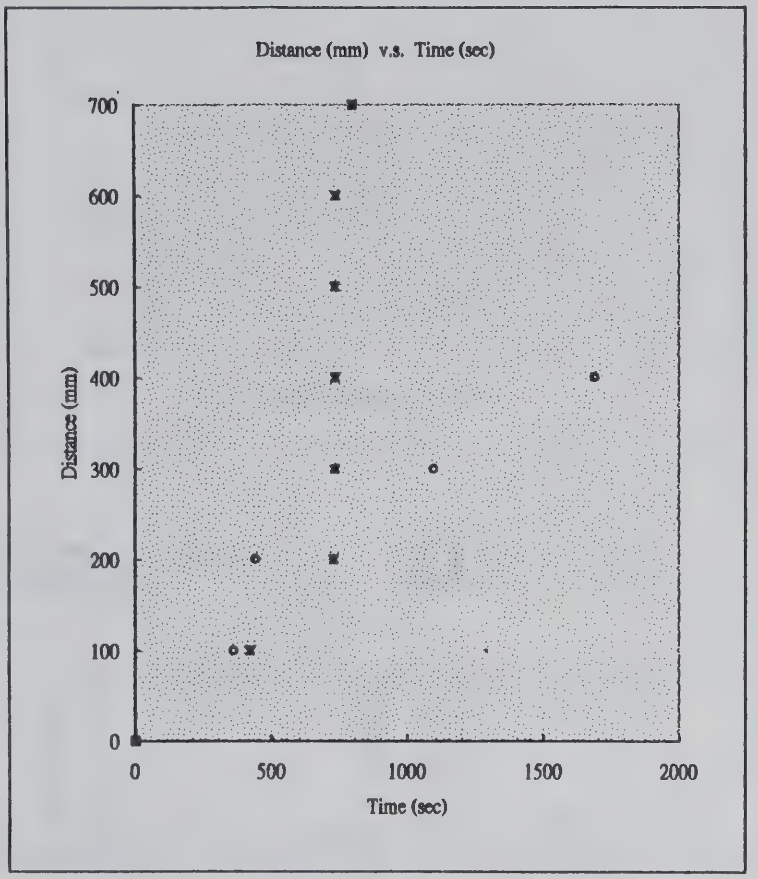
Table - 17 Roland 5-13 (FR EPS 80mm) Lateral Flame Spread

q" (kw/m^2)	Dis.(mm)	#1 (sec)	#2	#3	#4	#5	#6	q" F1(t)	q" F2(t)	q" F3(t)	q" F4(t)	q" F5(t)	q" F6(t)	V1	V2	V3	V4	V5	V6	1/sqrt(V1)	1/sqrt(V2)	1/sqrt(V3)	1/sqrt(V4)	1/sqrt(V5)	1/sqrt(V6)
24.3	0	4	3	3	3	3	3	4.1	3.5	3.5	3.5	3.5	3.5	---	---	---	---	---	---	---	---	---	---	---	---
19.6	100					424	363					19.6	19.6					0.27	0.40					1.92	1.58
13	200					732	446					13.0	13.0					0.49	0.23					1.43	2.10
8.5	300					737	1100					8.5	8.5					29.03	0.16					0.19	2.50
5	400					738	1693					5.0						64.29						0.12	
3.1	500					740						3.1						64.29						0.12	
1.9	600					741						1.9						2.42						0.64	
---	700					803		---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---

$k \cdot \rho \cdot c$	T,ig (K)	q",crit	h	b	t* (sec)	q"s,min	Ts,min (K)
0.557	763	25.7	0.055	0.084	143	1.2	345

Slope (Auto) = -0.05

Slope (Manual)	Φ — kw^2/m^3
-0.16	7.1



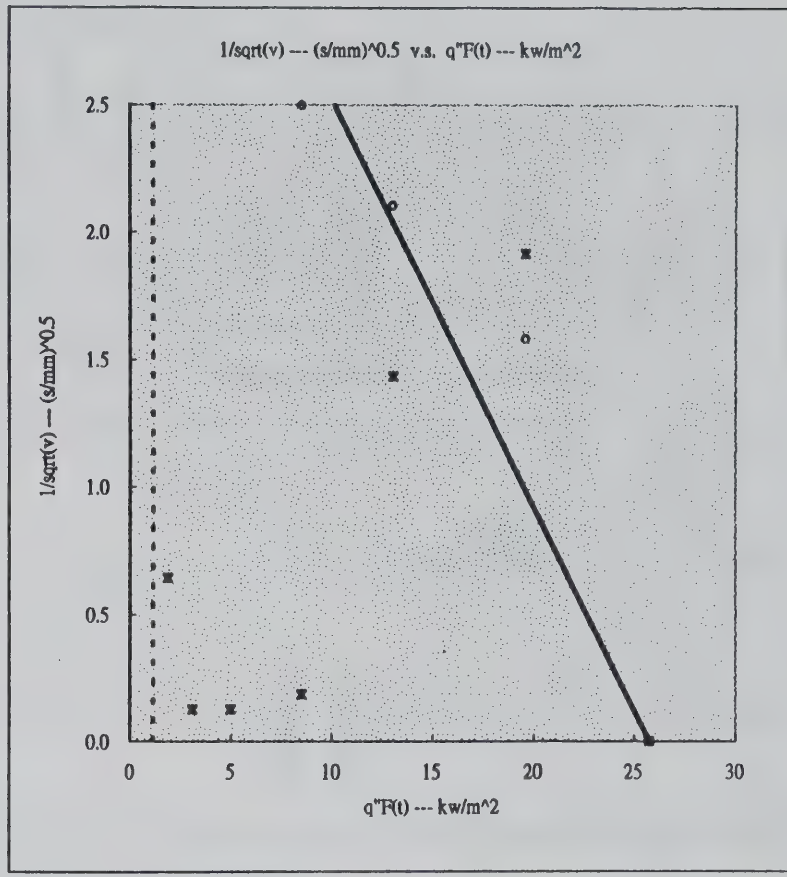
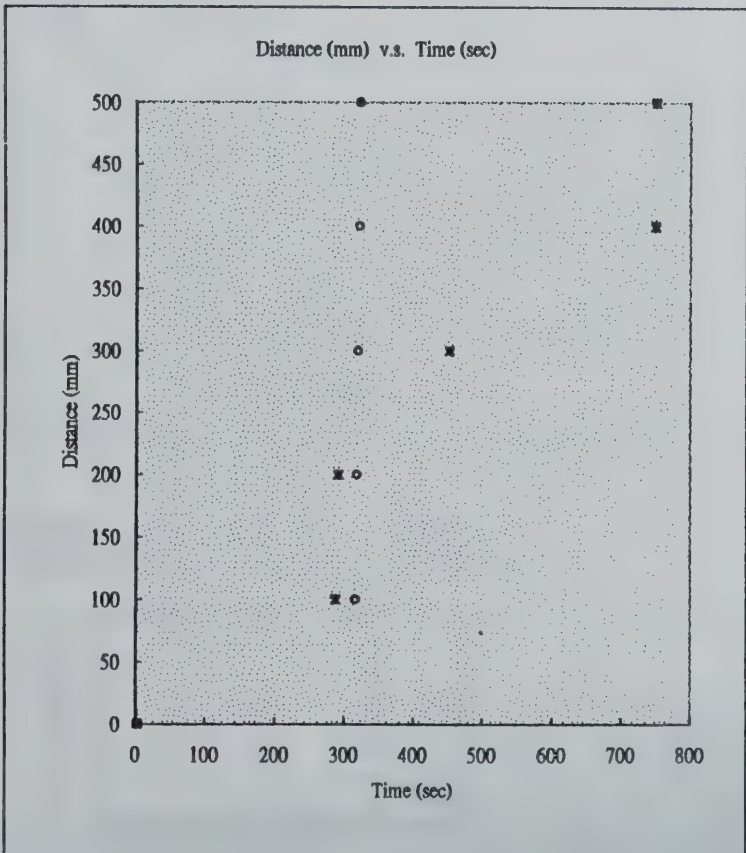
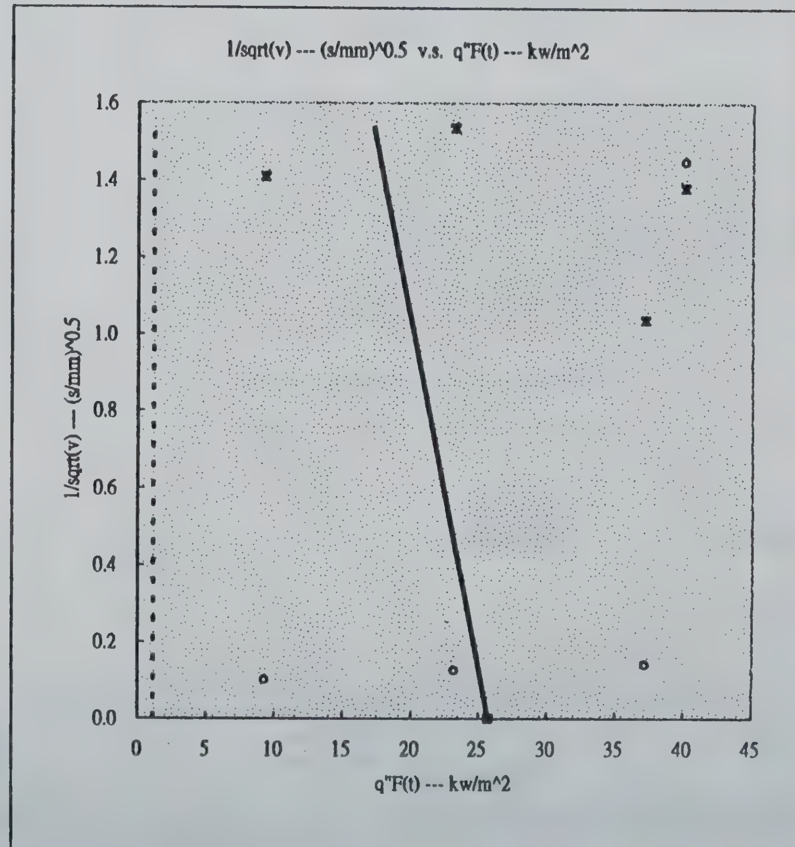


Table - 18 Roland 5-13 (FR EPS 80mm) Downward Flame Spread

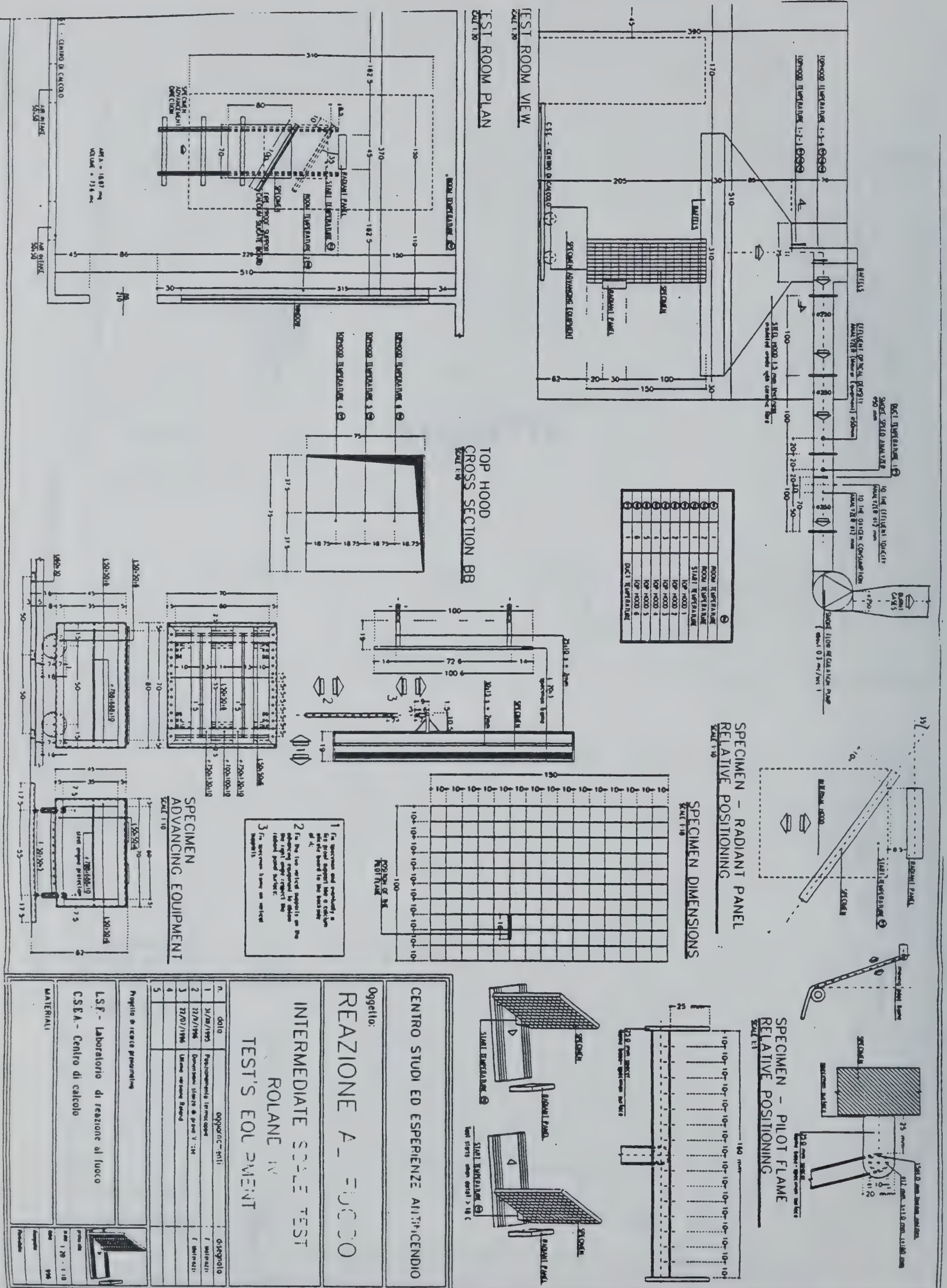
q" (kw/m^2)	Dis.(mm)	#1 (sec)	#2	#3	#4	#5	#6	q" F_1(t)	q" F_2(t)	q" F_3(t)	q" F_4(t)	q" F_5(t)	q" F_6(t)	V_1	V_2	V_3	V_4	V_5	V_6	1/sqrt(V_1)	1/sqrt(V_2)	1/sqrt(V_3)	1/sqrt(V_4)	1/sqrt(V_5)	1/sqrt(V_6)
31.0	0	4	3	3	3	3	3	5.2	4.5	4.5	4.5	4.5	4.5	---	---	---	---	---	---	---	---	---	---	---	---
40.1	100					288	317					40.1	40.1					0.5	0.5					1.38	1.45
37.2	200					292	319					37.2	37.2					0.9	50.0					1.04	0.14
23.2	300					453	321					23.2	23.2					0.4	64.3					1.54	0.12
9.3	400					750	322					9.3	9.3					0.5	100.0					1.41	0.10
---	500					751	323	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---

$k \cdot \rho \cdot c$	T,ig (K)	q",crit	h	b	t* (sec)	q"s,min	Ts,min (K)	Slope (Auto) =	Slope (Manual)	Φ-kw²/m³
0.557	763	25.7	0.055	0.084	143	1.2	345	---	-0.18	5.6



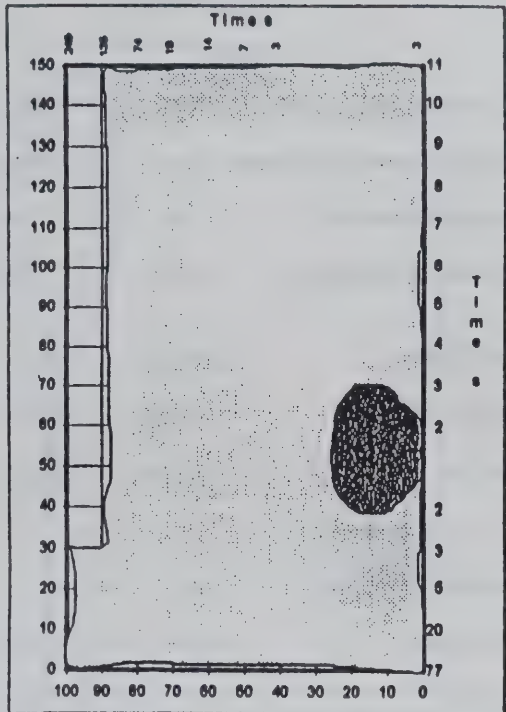


APPENDIX


TEST ROOM VIEW
TEST ROOM PLAN
TOP HOOD
CROSS SECTION BB
SPECIMEN - RADIANT PANEL
RELATIVE POSITIONING
SPECIMEN - PILOT FLAME
RELATIVE POSITIONING
SPECIMEN DIMENSIONS
SPECIMEN
ADVANCING EQUIPMENT
RADIANT PANEL
SPECIMEN
CENTRO STUDI ED ESPERIENZE ANTINCENDIO
Oggetto:
REAZIONE AL FUOCO
INTERMEDIATE SCALE TEST
ROLAND IV
TEST'S EQUIPMENT
n.
data
aggiornamenti
disegnato
Progetto di ricerca prenormativa
L.S.F.- Laboratorio di reazione al fuoco
C.S.E.A.- Centro di calcolo
MATERIALI

PUR WITH PAPER GLUED ON CALCIUM SILICATE 5.04

1ST SPECIMEN



TOTALLY DESTROYED AREA

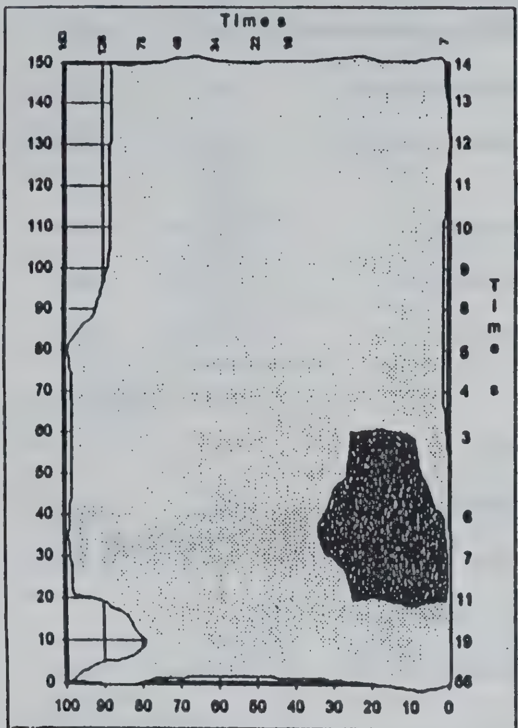
DAMAGED AREA (FLAMING)

SUMMARIZING LIST		
Dripping	(lev.)	1
Conditioned weight	(gr.)	13021.3
Weight after test	(gr.)	12309.5
Weight loss	(gr.)	711.8
Weight loss	(%)	5.5
Weight loss only PUR paper	(%)	30

Maximum flame spread upwards	mm.	1000
Maximum flame spread downwards	mm.	500
Maximum flame spread left	mm.	700
Maximum flame spread right	mm.	100
Critical flux upwards	kw/m2	<2.60
Critical flux downwards	kw/m2	<9.70
Critical flux left	kw/m2	<2.10
Time to ignition	s	1
Duration of flaming	s	695
Duration of test	s	930
Average flame spread upwards	mm/min.	6000
Average flame spread downwards	mm/min.	3101.05
Average flame spread lateral	mm/min.	974.16

PUR WITH PAPER GLUED ON CALCIUM SILICATE 5.04

2ND SPECIMEN



TOTALLY DESTROYED AREA

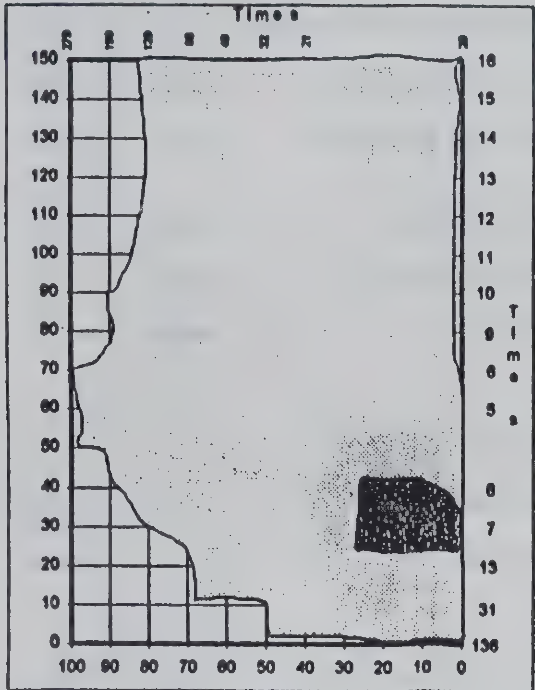
DAMAGED AREA (FLAMING)

SUMMARIZING LIST		
Dripping	(lev.)	1
Conditioned weight	(gr.)	12235.5
Weight after test	(gr.)	11624.1
Weight loss	(gr.)	611.4
Weight loss	(%)	5
Weight loss only PUR paper	(%)	25.5

Maximum flame spread upwards	mm.	1000
Maximum flame spread downwards	mm.	500
Maximum flame spread left	mm.	700
Maximum flame spread right	mm.	100
Critical flux upwards	kw/m2	<2.60
Critical flux downwards	kw/m2	<9.70
Critical flux left	kw/m2	<2.10
Time to ignition	s	2
Duration of flaming	s	814
Duration of test	s	1229
Average flame spread upwards	mm/min.	5600
Average flame spread downwards	mm/min.	1975.5
Average flame spread lateral	mm/min.	411.81

PUR WITH PAPER GLUED ON CALCIUM SILICATE 5.04

3RD SPECIMEN



TOTALLY DESTROYED AREA

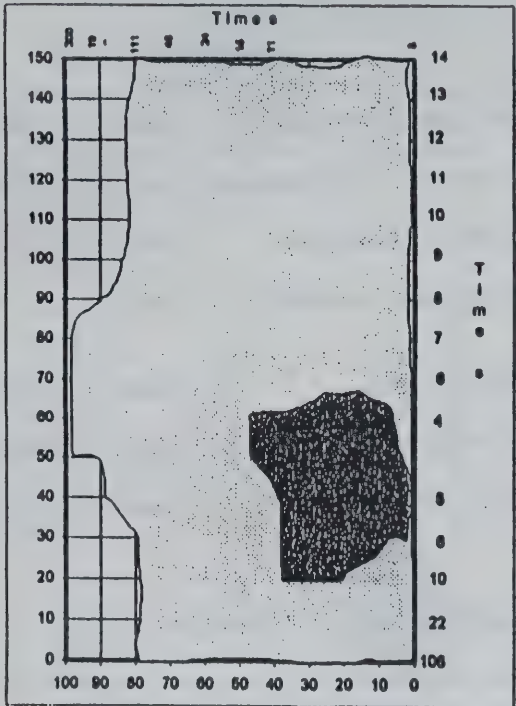
DAMAGED AREA (FLAMING)

SUMMARIZING LIST		
Dripping	(lev.)	1
Conditioned weight	(gr.)	12562.4
Weight after test	(gr.)	12261.7
Weight loss	(gr.)	300.7
Weight loss	(%)	2.4
Weight loss only PUR paper	(%)	12.5

Maximum flame spread upwards	mm.	1000
Maximum flame spread downwards	mm.	500
Maximum flame spread left	mm.	700
Maximum flame spread right	mm.	100
Critical flux upwards	kw/m2	<2.60
Critical flux downwards	kw/m2	<9.70
Critical flux left	kw/m2	<2.10
Time to ignition	s	4
Duration of flaming	s	670
Duration of test	s	1508
Average flame spread upwards	mm/min.	5800
Average flame spread downwards	mm/min.	2078.1
Average flame spread latereal	mm/min.	245.54

PUR WITH PAPER GLUED ON CALCIUM SILICATE 5.04

4TH SPECIMEN




TOTALLY DESTROYED AREA


DAMAGED AREA (FLAMING)

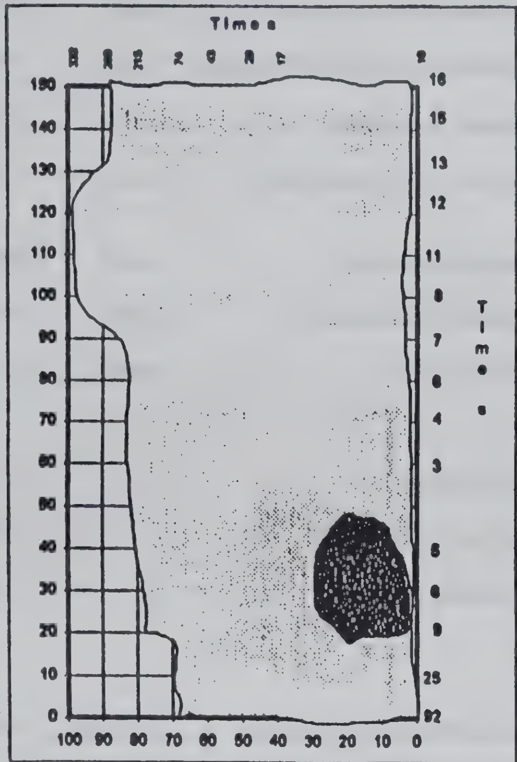
SUMMARIZING LIST

Dripping	(lev.)	1
Conditioned weight	(gr.)	12781.2
Weight after test	(gr.)	12234.3
Weight loss	(gr.)	546.9
Weight loss	(%)	4.3
Weight loss only PUR paper	(%)	23

Maximum flame spread upwards	mm.	1000
Maximum flame spread downwards	mm.	500
Maximum flame spread left	mm.	700
Maximum flame spread right	mm.	100
Critical flux upwards	kw/m2	<2.60
Critical flux downwards	kw/m2	<9.70
Critical flux left	kw/m2	<2.10
Time to ignition	s	3
Duration of flaming	s	699
Duration of test	s	1346
Average flame spread upwards	mm/min.	5700
Average flame spread downwards	mm/min.	2214.3
Average flame spread lateral	mm/min.	484.62

PUR WITH PAPER GLUED ON CALCIUM SILICATE 5.04

5TH SPECIMEN



TOTALLY DESTROYED AREA

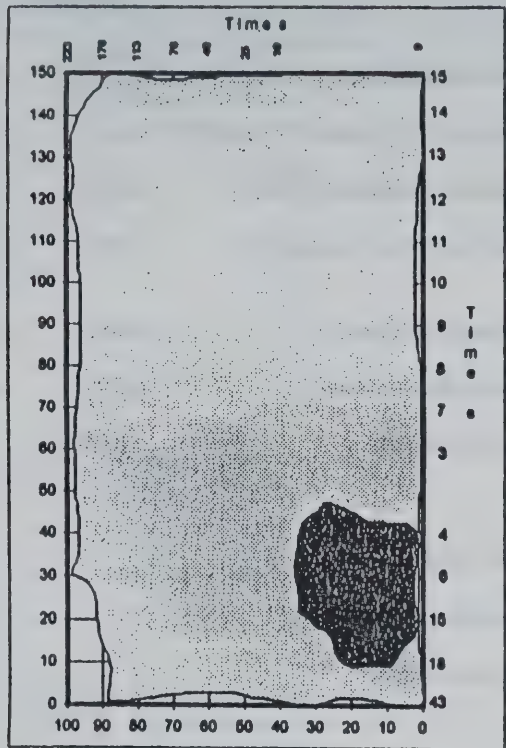
DAMAGED AREA (FLAMING)

SUMMARIZING LIST		
Dripping	(lev.)	1
Conditioned weight	(gr.)	12661.6
Weight after test	(gr.)	11903
Weight loss	(gr.)	758.6
Weight loss	(%)	6
Weight loss only PUR paper	(%)	31.6

Maximum flame spread upwards	mm.	1000
Maximum flame spread downwards	mm.	500
Maximum flame spread left	mm.	700
Maximum flame spread right	mm.	100
Critical flux upwards	kw/m2	<2.60
Critical flux downwards	kw/m2	<9.70
Critical flux left	kw/m2	<2.10
Time to ignition	s	2
Duration of flaming	s	749
Duration of test	s	1348
Average flame spread upwards	mm/min.	5000
Average flame spread downwards	mm/min.	2092.9
Average flame spread lateral	mm/min.	257.83

PUR WITH PAPER GLUED ON CALCIUM SILICATE 5.04

6TH SPECIMEN



TOTALLY DESTROYED AREA

DAMAGED AREA (FLAMING)

Maximum flame spread upwards	mm.	1000
Maximum flame spread downwards	mm.	500
Maximum flame spread left	mm.	700
Maximum flame spread right	mm.	100
Critical flux upwards	kw/m2	<2.60
Critical flux downwards	kw/m2	<0.70
Critical flux left	kw/m2	<2.10
Time to ignition	s	2
Duration of flaming	s	723
Duration of test	s	1321
Average flame spread upwards	mm/min.	5550
Average flame spread downwards	mm/min.	1781.33
Average flame spread lateral	mm/min.	329.23

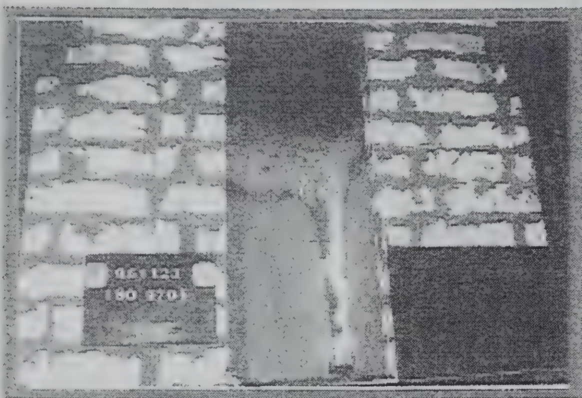
SUMMARIZING LIST

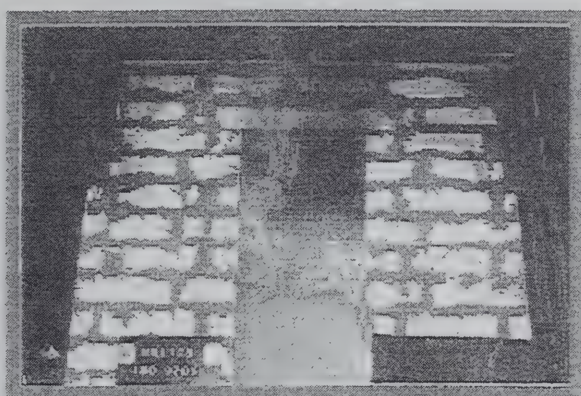
Dripping	(lev.)	1
Conditioned weight	(gr.)	12265.9
Weight after test	(gr.)	11840.4
Weight loss	(gr.)	425.5
Weight loss	(%)	3.5
Weight loss only PUR paper	(%)	17.7

Appendix C – Thureson, Per, "Fire Tests of Linings According to Room/Corner Test, ISO 9705", Swedish National Testing and Research Institute, Fire Technology, Report 95R22049, January, 1996.

SP - Fire Technology

Fire tests of linings according to Room/Corner Test, ISO 9705





Sponsored by the Ministero dell'Interno and LSF, Italy, for the Roland programme

SP
Swedish National Testing and Research Institute
Fire Technology
REPORT 95R22049, January 1996

L.S.F Fire LABORATORIES
Via Garibaldi, 28/A
22070 Montano Lucino (CO)
ITALY

Handläggare, enhet/*Handled by, department*	Datum/Date	Beteckning/Reference	Sida/Page
Per Thureson, Fire Technology Tel +46 (0)33 16 50 83	1996-01-26	95R22049	1 (5)

Heat release and smoke production of building products when tested according to the Room/Corner Test, ISO 9705

(14 enclosures)

SP - Fire Technology has by the order of LSF performed a series of tests of linings according to the Room/Corner Test, ISO 9705. The purpose of the tests was to evaluate the burning behaviour of the products.

Products

Twelve building products were tested. They are described in enclosure 1.

The products were delivered to SP during November-1995. Products no 1-8 were delivered from DBi, Denmark. Products no 9-12 were delivered by LSF. It is not known to SP if the products received are representative of the mean production characteristics.

Test procedure

The Room/Corner Test - ISO 9705:

The test room is constructed from aerated concrete and has the following nominal inner dimensions; 3.6 m x 2.4 m x 2.4 m (length x width x height). There is a doorway in the centre of one of the 2.4 m x 2.4 m walls. The material is mounted on the walls and in the ceiling of the test room. A gas burner having the dimensions 170 mm x 170 mm x 145 mm is placed on the floor in the right corner opposite the doorway, see figure 1.

The smoke produced by the burning specimen is collected by the exhaust hood and evacuated through the exhaust duct. By continuously analysing the oxygen (O_2) and carbon dioxide (CO_2) content of the smoke gases, the developed heat release rate can be calculated. The optical density of the smoke is measured continuously throughout the test with a white light system.

The test duration is 20 minutes. During the first 10 minutes the heat output from the burner is 100 kW. Thereafter the output level is increased to 300 kW for another 10 minutes. If flashover occurs the fire is extinguished.

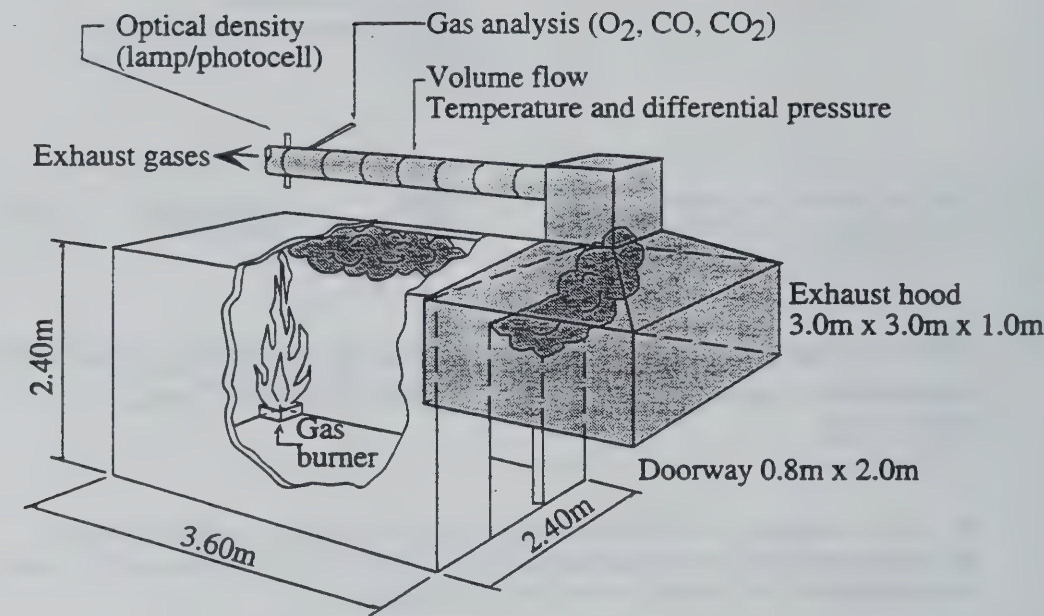


Figure 1 Schematic drawing of the ISO 9705 room test.

Surface temperatures:

The surface temperatures of the test samples in the ceiling and on the right wall (viewed from the door opening) were measured with thermocouples, 0.25 mm thick lead wires of type K (NiCr-NiAl). Five thermocouples were mounted in the ceiling and another five were mounted on the upper part of the wall. The positioning of the thermocouples was according to figure 2. The hot junction of the thermocouple was fixed in contact with the surface of the wall/ceiling by means of non combustible tape. The lead wires were led through the wall and ceiling of the room, close to the hot junction.

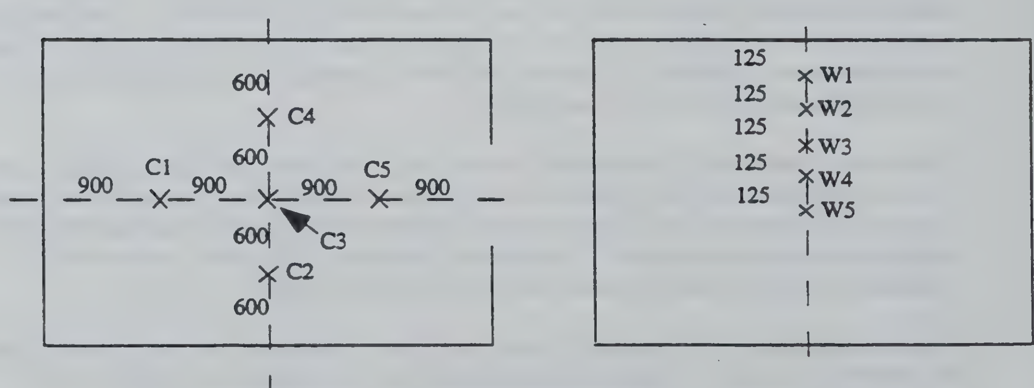


Figure 2 Positioning of thermocouples in the ceiling (left) and on the wall (right) (measures in mm).

Heat flux measurements:

Heat flux measurements were made using total heat flux gauges that were facing the burner corner. Two heat flux gauges were mounted along the diagonal of the room at a distance of 1m and 2 m measured from the burner corner. The gauge at 2 m distance was mounted at 1.2 m above floor level. The other gauge, closer to the burner corner, was mounted at 0.8 m above floor level. The sensing surfaces were vertically oriented and facing directly the burner corner.

Test results

Tabulated test results are given in enclosure 1. Detailed information is given for each test in enclosures 2-13, including

-logs of test observations
-graphs of heat release rate (HRR)
-graphs of smoke production rate (SPR)
-graphs of carbon monoxide production rate
-graphs of surface temperatures
-graphs of heat flux
-photographs

Test results from a calibration test are given in enclosure 14.

Summary and comments

The performed test series showed that ISO 9705 is suitable for ranking products in a scientific sound way. Measured heat release rates from all the products are shown in figures 3-4. It is seen that the method accurately can measure the burning behaviour of very different products. The hood system used was capable of very accurate measurements ranging from 5 kW to 2000 kW (see also enclosure 14). Thus even very limited combustion can be detected.

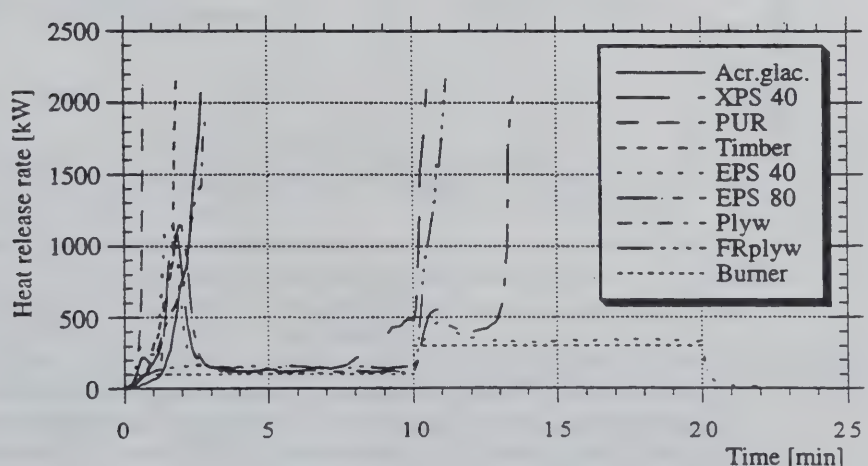


Figure 3 Products that reached HRR peaks exceeding 1000 kW .

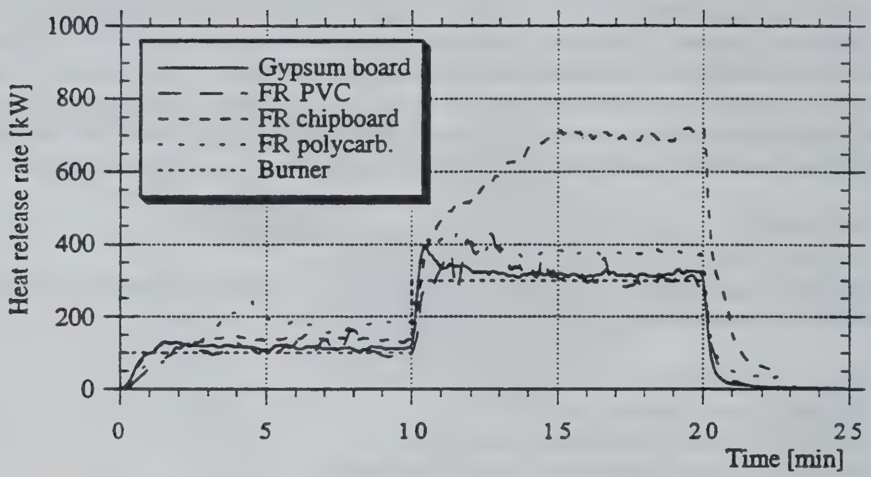


Figure 4 Products that showed limited burning i.e. had HRR peaks lower than 1000 kW .

The ignition regime of the ISO 9705:

The need of the second, more severe, heat output level (300 kW) of the burner to achieve the required discrimination is clearly demonstrated by comparing the heat release rate history of for example FR plywood and Gypsum board, see figure 5. Until the increase in burner heat output the behaviour of the products are quite similar, while the FR plywood shows a rapid fire growth rate after the burner heat output is increased.

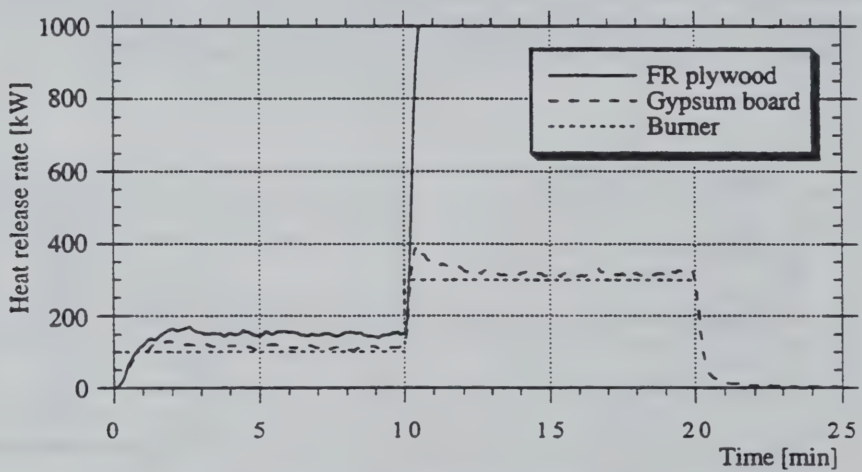


Figure 5 A comparison of the heat release rate history of FR plywood and Gypsum board. The 100 kW burner level is hardly capable of separating the burning behaviour of those products. However after the increase in burner heat output to 300 kW the difference in combustion properties is clearly seen.

The same conclusion can be drawn from the three polystyrenes test results. During the first ten minutes of the tests the polystyrenes behaved quite similar with HRR peaks at about 1000 kW, see figure 6.

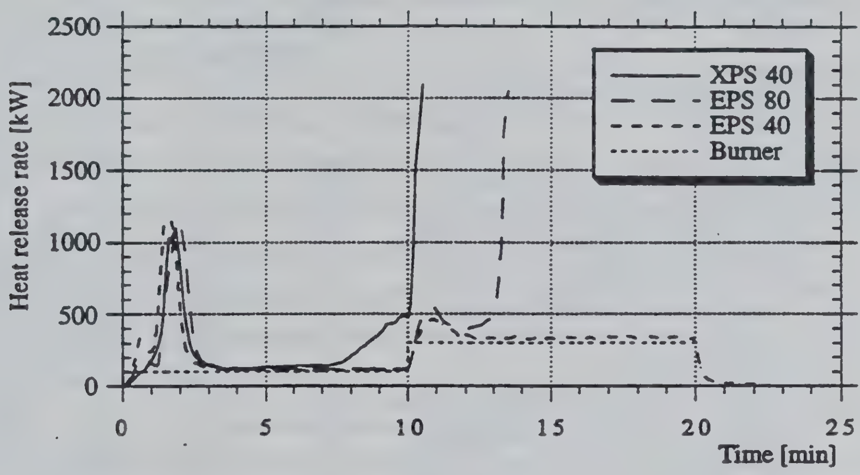


Figure 6 Heat release rates of the three tested polystyrenes. The burning rates are quite similar during the first period of the tests. However after increase of the burner heat output the differences in burning behaviour are clearly seen .

However after the burner heat output was increased at 10 minutes two of the polystyrenes showed more than 1000 kW HRR but clearly separated in time. The third product showed only limited burning.

Sveriges Provnings- och Forskningsinstitut
Fire Technology, Materials Reaction-to-Fire

Björn Sundström
Head of Section

Per Thureson
Technical officer

Enclosures

1 Tabulated test results and list of tested products
2 Paper-faced gypsum board, test results
3 FR PVC, test results
4 Acrylic glazing, test results
5 FR extruded polystyrene board, 40 mm, test results
6 PUR foam panel with aluminium faced paper finish, test results
7 Mass timber, varnished, test results
8 FR chipboard, test results
9 3-layered FR polycarbonate panel, test results
10 FR expanded polystyrene board, 40 mm, test results
11 FR expanded polystyrene board, 80 mm, test results
12 Plywood, test results
13 FR plywood, test results
14 Calibration test results

Products and test results, tabulated data

Table 1 Tested products

	Type of material	Nominal thickness [mm]	Nominal density [kg/m³]
1	Paper-faced gypsum board	13	700
2	FR PVC	3	1450
3	Acrylic glazing (transparent)	3	1180
4	FR extruded polystyrene board	40	33
5	PUR foam panel with al paper	40	40 (PUR)
6	Mass timber (pine), varnished	15	-*
7	FR chipboard	12	780
8	3-layered FR polycarbonate panel	16	1200
9	FR expanded polystyrene board	40	30
10	FR expanded polystyrene board	80	15
11	Plywood	14	-*
12	FR plywood	15	-*

*No data given by the client. Measured data are given in enclosures.

Table 2 Heat, smoke and carbon monoxide production.

Type of material	Time to 1000 kW or time to peak HRR if the fire was smaller than 1000 kW [min:s]	Peak HRR excluding the burner output [kW]	Peak SPR [m²/s]	Peak CO [g/s]
Gypsum board	10:26	94	0.5	0.5
FR PVC	12:41	129	2.6	0.6
Acrylic glazing	2:16	> 1000	1.1	3.3
FR extr. PS 40 mm	1:36	> 1000	39.0	11.8
PUR foam with al pap.	0:41	> 1000	21.9	9.1
Mass timber	1:46	> 1000	32.8	17.5
FR chipboard	20:00	423	17.4	15.8
3 layer FR polycarbon.	11:36	132	2.1	0.4
FR exp. PS 40 mm	1:26	> 1000	14.8	12.5
FR exp. PS 80 mm	1:46	> 1000	6.2	12.0
Plywood	2:21	> 1000	16.6	16.4
FR Plywood	10:31	> 1000	12.2	16.6

Table 3 Heat, smoke and carbon monoxide production, accumulated data (all data are calculated from start of test until the HRR reached 1000 kW or to the end of the test duration)

Type of material	THR [MJ]	TSP [m^2]	Tot CO [g]	TSP/THR [m^2/MJ]
Gypsum board	17	255	224	15
FR PVC	12	1102	261	92
Acrylic glazing	20	19	92	1
FR extr. PS 40 mm	21	464	195	22
PUR foam with al pap.	12	135	60	11
Mass timber	26	523	336	20
FR chipboard	210	7798	7680	37
3 layer FR polycarbon.	80	1105	216	14
FR exp. PS 40 mm	27	180	415	7
FR exp. PS 80 mm	30	91	376	3
Plywood	37	331	676	9
FR Plywood	34	176	493	5

The polystyrenes behaved similar during the first part of the test. A peak HRR just exceeding 1000 kW was seen quite early, see figure 6 (main report). However after the first peak HRR the fire decreased for all polystyrenes and a second peak occurred later on after the increase of the burner heat output. Therefore data are also given for the polystyrenes for the entire test duration, see table 4.

Table 4 Polystyrenes, heat, smoke and carbon monoxide production. The values are given until the second time the HRR reached 1000 kW or to the end of the test duration (EPS 40 mm)

Type of material	Time to 1000 kW during the first part of the test 0-10 min [min:s]	Time to 1000 kW during the second part of the test 10-20 min [min:s]	THR until the fire reached 1000 kW during the second part of the test or to end of test [MJ]	Peak SPR during the entire test duration [m^2/s]	TSP until the fire reached 1000 kW during the second part of the test or to end of test [m^2]	Tot CO until the fire reached 1000 kW during the second part of the test or to end of test [g]
XPS 40 mm	1:36	10:16	98	49.2	3275	799
EPS 40 mm	1:26	-	84	28.4	1661	793
EPS 80 mm	1:46	13:21	101	27.3	1746	987

Legend

Time to : 1000 kW Time at which the total heat release rate reached 1000 kW (including the burner heat output) corresponding with flashover in the room.

Peak HRR: Maximum heat release rate for the entire test duration if no flashover occurred (excluding the HRR from the ignition source). For tests where flashover occurred this value cannot be given since the fire had to be extinguished.

THR: Total heat released during the entire test for tests where no flashover occurred (excluding the HRR from the ignition source). For tests where flashover occurred the heat release rate is integrated from the beginning of the test till flashover.

Peak SPR: Maximum smoke production rate for the entire test duration if no flashover occurred. For tests where flashover occurred this value is given at flashover. The smoke production rate is calculated as follows:

$$SPR = \frac{1}{L} * \ln\left(\frac{I_0}{I}\right) * \dot{V}$$

Where

$\dot{V}$ is the volumetric flow rate in the duct at actual temperature (m^3/s)
L is the optical path length in the duct (m)
I_0 is the initial intensity of a light beam
I is the intensity of the light beam after traversing a smoky environment

TSP: Total smoke production during the entire test for tests where no flashover occurred. The total smoke production is integrated from the smoke production rate. For tests where flashover occurred the smoke production is integrated from the beginning of the test till flashover.

Peak CO: Maximum CO production rate for the entire test duration if no flashover occurred. For tests where flashover occurred this value is given till flashover (including any contribution from the ignition source).

Tot CO: Total CO production during the entire test for tests where no flashover occurred. The total CO production is integrated from the CO production rate. For tests where flashover occurred the CO production is integrated from the beginning of the test till flashover.

TSP/THR: Total smoke production divided by the total heat released.

Table 5 Heat flux measurements. The heat flux gauges were mounted along the diagonal of the room, facing the burner corner, at a distance of 1 m and 2 m measured from the corner.

Material	Maximum Heat Flux 1m [kW/m^2]	Maximum Heat Flux 2m [kW/m^2]	Maximum Heat Flux 1m till FO [kW/m^2]	Maximum Heat Flux 2m till FO [kW/m^2]
Gypsum board	16.8	9.9	NA	NA
FR PVC	13.6	10.6	NA	NA
Acrylic glazing	FO	FO	32.9	17.5
FR extruded PS 40 mm	FO	FO	45.3	17.2
PUR foam with al paper	FO	FO	32.7	31.1
Mass timber	FO	FO	12.6	19.5
FR chipboard	24.7	23.4	NA	NA
3 layer FR polycarbonate	18.6	12.8	NA	NA
FR expanded PS 40 mm	FO	FO	15.5	15.8
FR expanded PS 80 mm	FO	FO	44.3	19
Plywood	*	*	*	*
FR Plywood	*	*	*	*

Legend

FO : Flashover

NA: Not appropriate.

* : No heat flux meters were installed.

Maximum Heat flux 1m: Maximum heat flux during the entire test recorded by a total heat flux meter positioned 1 m from the burner (including the contribution from the ignition source). Tests where flashover occurred are not reported.

Maximum Heat flux 2m: Maximum heat flux during the entire test recorded by a total heat flux meter positioned 2 m from the burner (including the contribution from the ignition source). Tests where flashover occurred are not reported.

Maximum Heat flux 1m till FO: Maximum heat flux till flashover recorded by a total heat flux meter positioned 1 m from the burner (including the contribution from the ignition source). In most cases this will be the heat flux at flashover.

Maximum Heat flux 2m till FO: Maximum heat flux till flashover recorded by a total heat flux meter positioned 2 m from the burner (including the contribution from the ignition source). In most cases this will be the heat flux at flashover.

Test results, ISO 9705 (NT FIRE 025)

Product

Paper-faced gypsum board.

Mounting

The gypsum boards were nailed to the lightweight concrete walls and ceiling.

Observations during test.

Time, [min:s]	Observations
0:00	Ignition of the burner, 100 kW.
0:00-10:00	Very limited HRR and SPR. The paper surface was charred to an extent of approximately 1.5 m^2.
10:00	The burner output was increased to 300 kW. Some flame spread was seen on the ceiling after increase of the burner heat output, see photo no 3.
20:00	The test was terminated. The paper surface was charred to an extent of approximately 5 m^2.
After test:	Charred areas, see photo no 5 and 6.

Measured data

Thickness, mm	12.6
Density, kg/m^3	720

Conditioning

Temperature 20 ± 5 °C

Test results, graphs

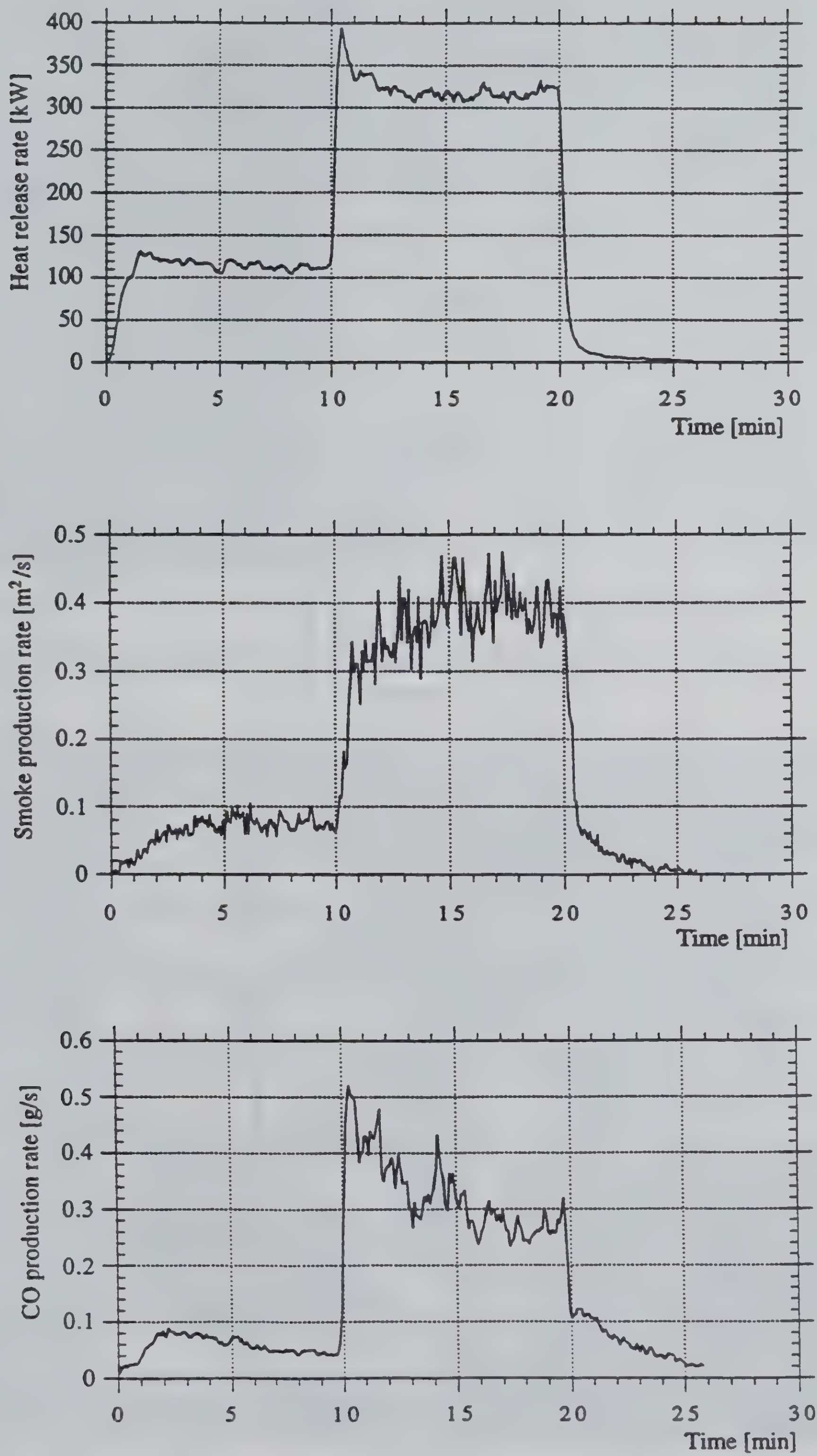


Figure 1 Paper-faced gypsum board, heat release rate (including the HRR from the ignition source), smoke production rate and carbon monoxide production rate

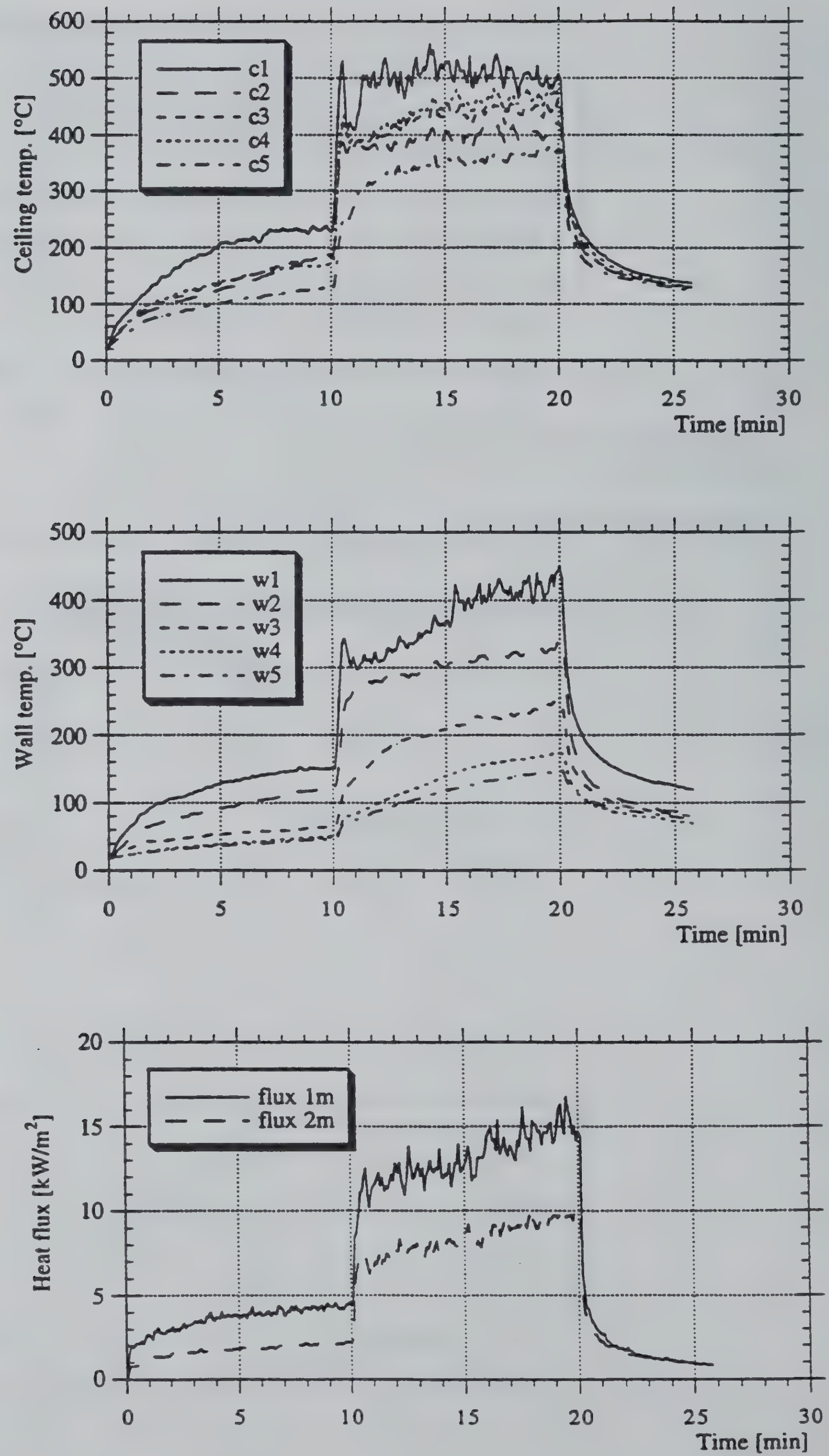


Figure 2 Paper-faced gypsum board, ceiling temperatures, wall temperatures and heat flux, including the contribution from the ignition source.

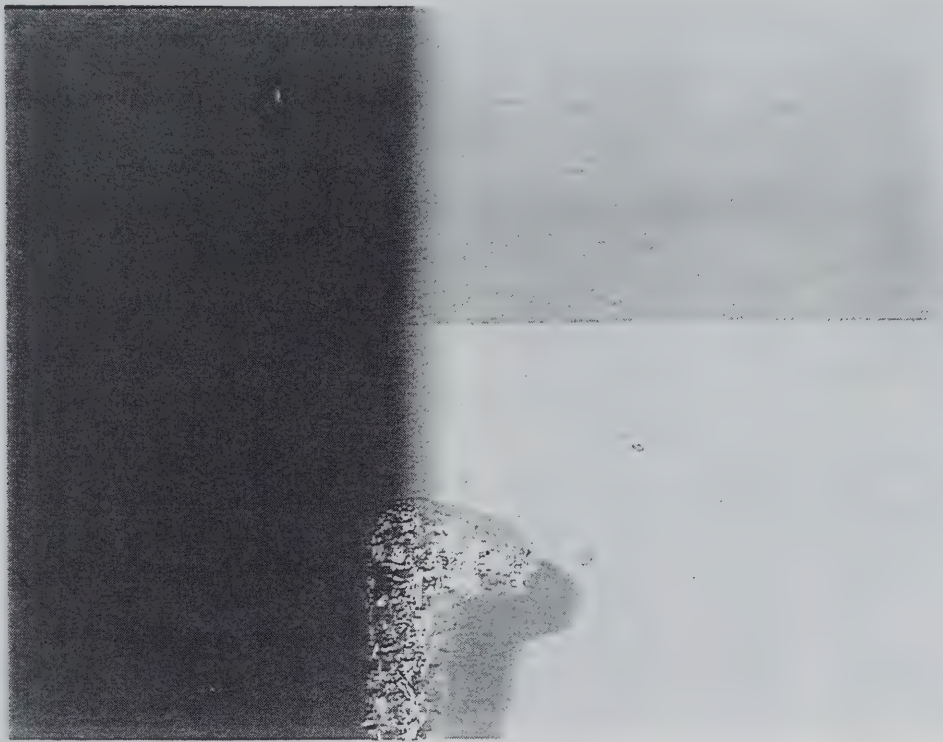


Photo no 1 Prior to test "Paper faced gypsum board"

The paper faced gypsum board were nailed to the lightweight concrete walls and ceiling.

Photo no 2 Time 2:14 "Paper faced gypsum board"

Very limited HRR and SPR (by request from the client standard polyether foam blocks were placed at three positions on the floor prior to start of test).

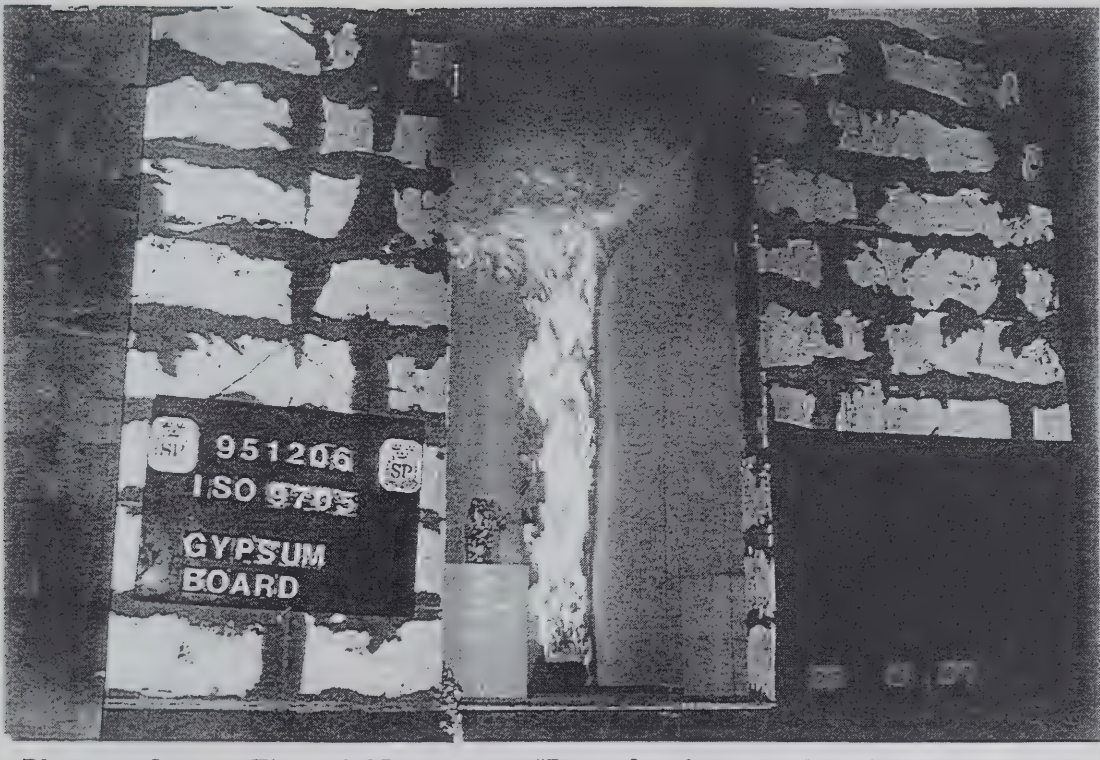


Photo no 3 Time 10:07 "Paper faced gypsum board"

The burner output had been increased to 300 kW. Some flame spread was seen in the ceiling after increase of the burner heat output.

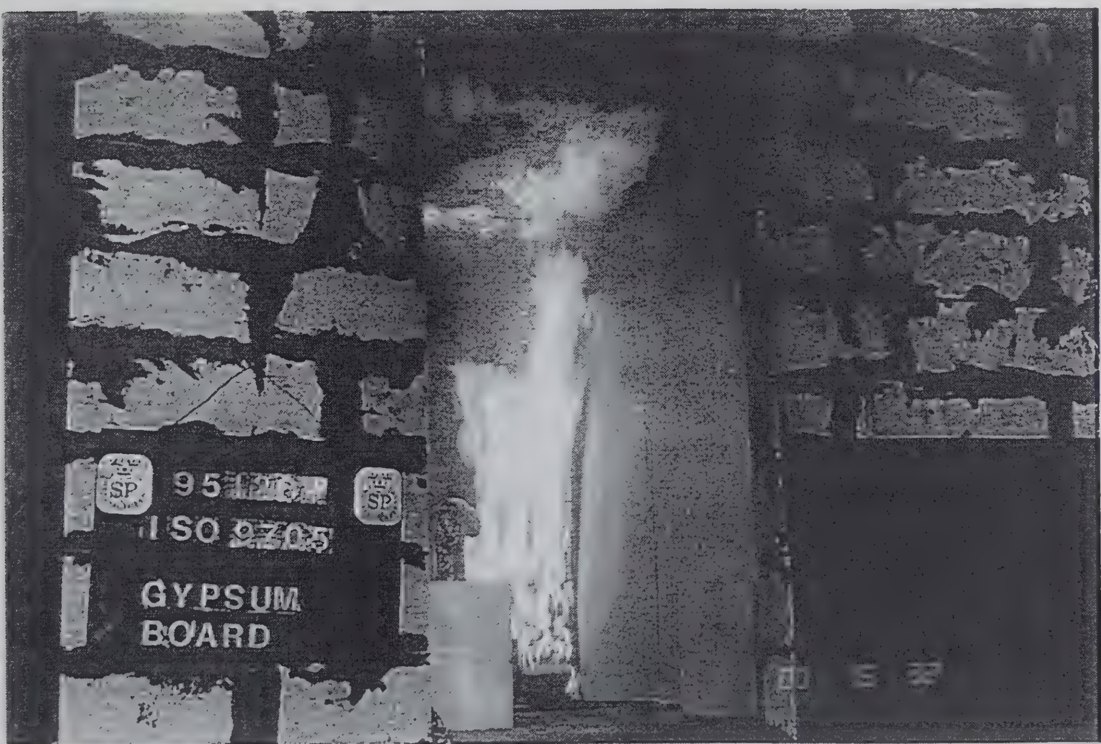


Photo no 4 Time 15:32 "Paper faced gypsum board"

Still very limited HRR and SPR.

Photo no 5 After test "Paper faced gypsum board"

Most parts of the ceiling and the walls were undamaged. The paper surface was burnt or charred to an extent of approximately 5 m^2.

Photo no 6 After test "Paper faced gypsum board"

Damaged areas in the ceiling.

Test results, ISO 9705 (NT FIRE 025)

Product

FR PVC

Mounting

The PVC panels were screwed to a frame of light steel profiles which gave a spacing of 40 mm to the light weight concrete walls and ceiling.

Observations during test.

Time, [min:s]	Observations
0:00	Ignition of the burner, 100 kW.
0:30	The ceiling panel above the burner began to deform, see photo no. 2.
1:10	A smoke gas layer was formed. The ceiling was no longer visible, see photo no. 3
1:25	The material melted at the burner corner.
9:00	Most of the ceiling material was melted (softened) and had fallen down onto the floor. HRR and SPR were limited
10:00	The burner output was increased to 300 kW.
11:00	All ceiling panels were softened and had fallen down.
20:00	Gas shut off.
After test:	Not much material had been consumed. Most wall and ceiling panels had melted or just softened and were laying on the floor, see photo no 6.

Comments to the graphs

The accuracy of the HRR measurement was ±10% due to noise pick-up in the analysers.

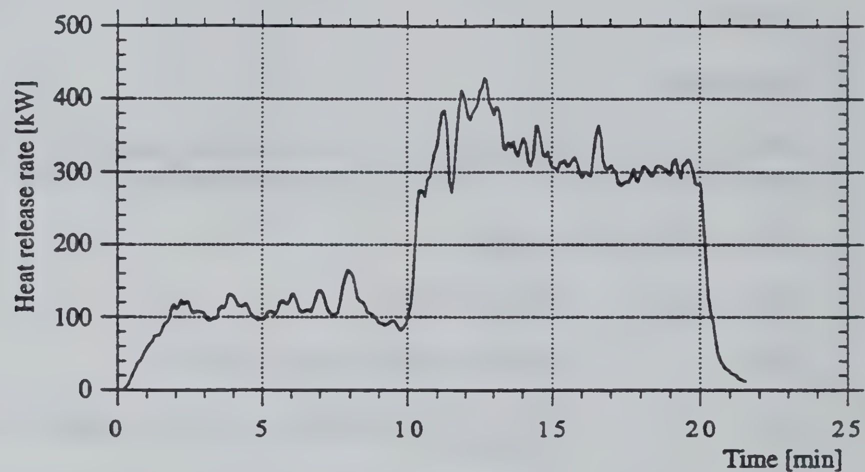
Measured data

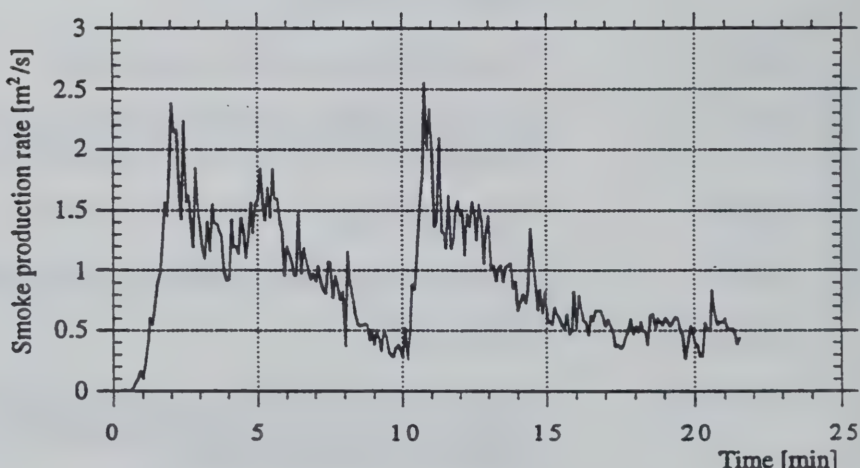
Thickness, mm	3.0
Density, kg/m^3	1505

Conditioning

Temperature 20 ± 5 °C

Test results, graphs





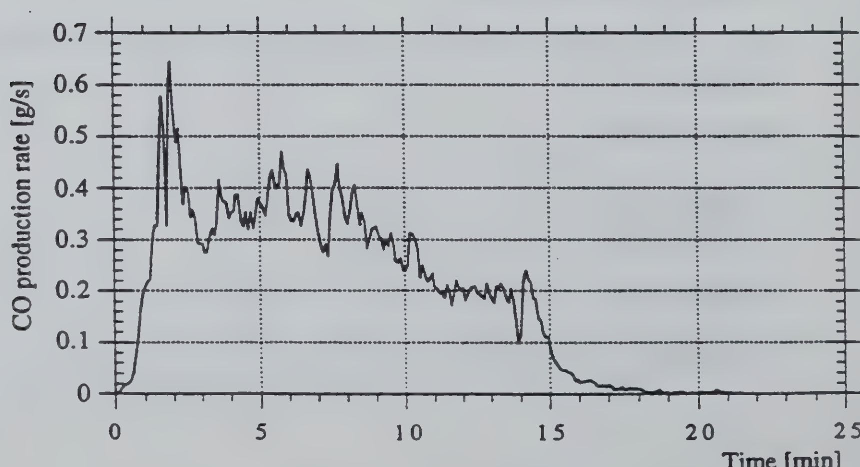


Figure 1 FR PVC, heat release rate (including the HRR from the ignition source), smoke production rate and carbon monoxide production rate

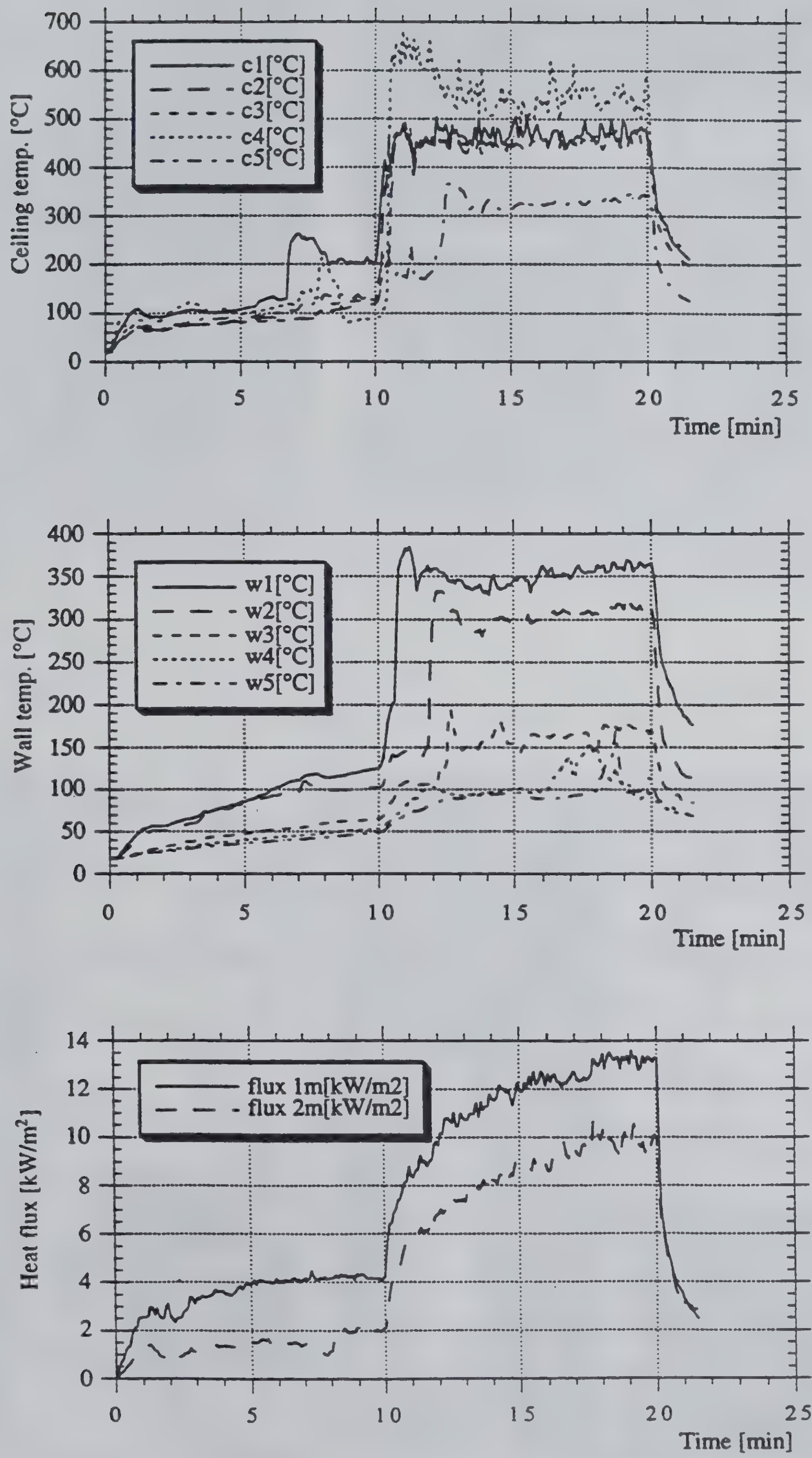


Figure 2 FR PVC, ceiling temperatures, wall temperatures and heat flux, including the contribution from the ignition source.

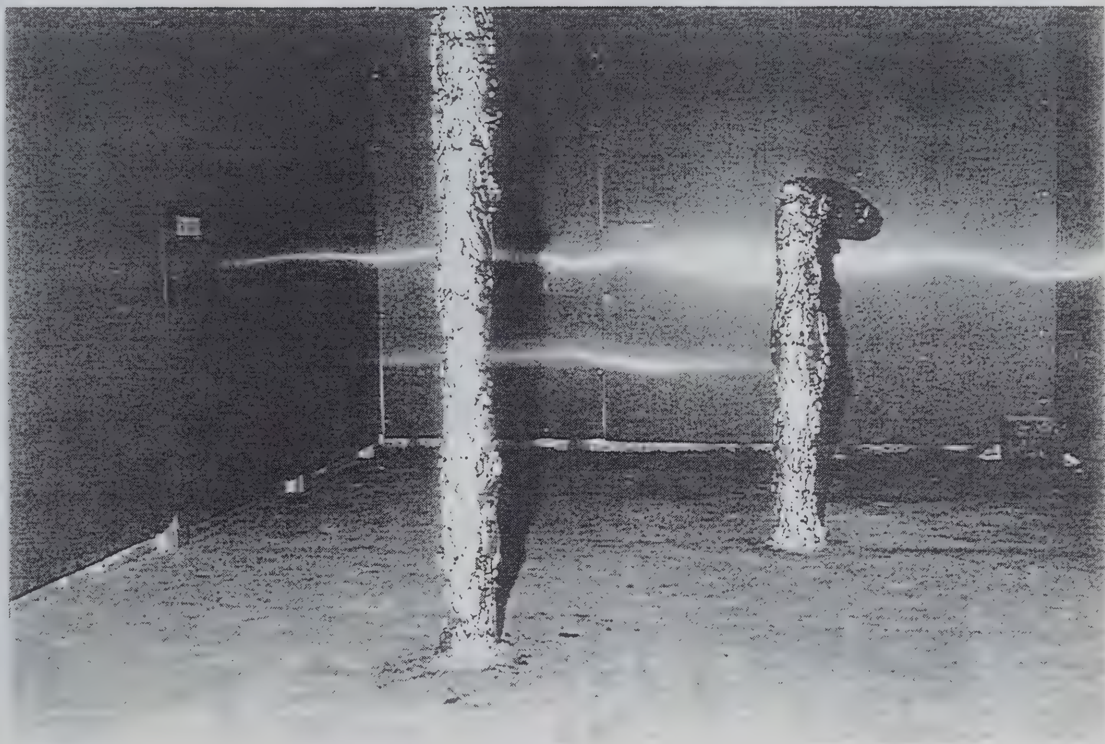


Photo no 1 Prior to test "FR PVC"

The PVC panels were screwed to a frame of light steel profiles which provided for a spacing of 40 mm to the light weight concrete walls and ceiling.

Photo no 2 Time 0:32 "FR PVC"

The ceiling panel above the burner started to get deformed.

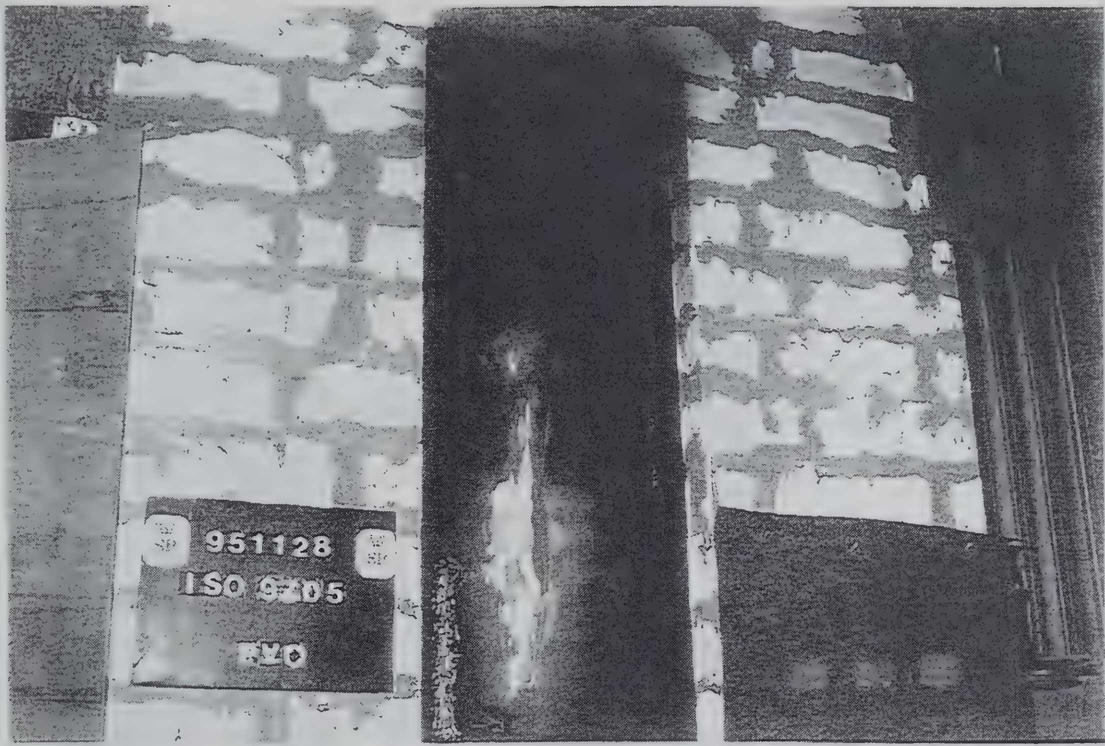


Photo no 3 Time 1:06 "FR PVC"

A smoke gas layer was formed. The ceiling was no longer visible.

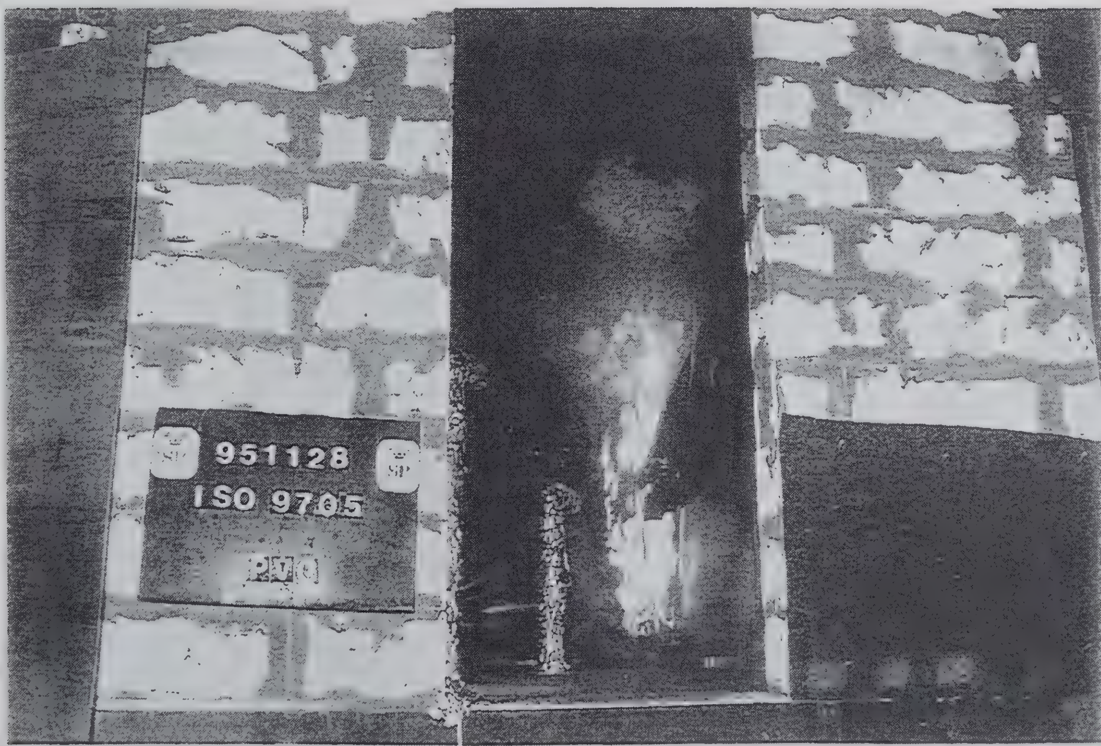


Photo no 4 Time 10:08 "FR PVC"

The burner heat output had been increased to 300 kW. Large portions softened and fell down on the floor. Flaming in the material were only seen in the vicinity of the burner.

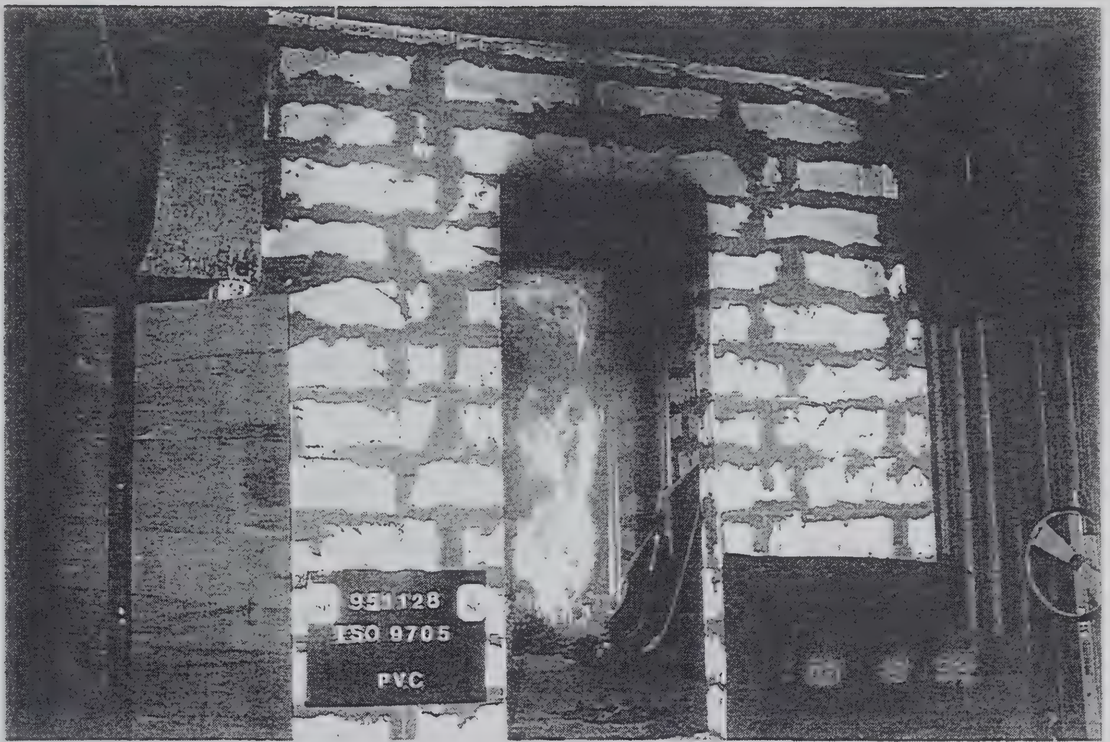


Photo no 5 Time 19:58 "FR PVC"

Close to gas shut off. Limited HRR and SPR, burning only in the burner corner. The material in the ceiling and most material on the walls had softened and fallen down on the floor.

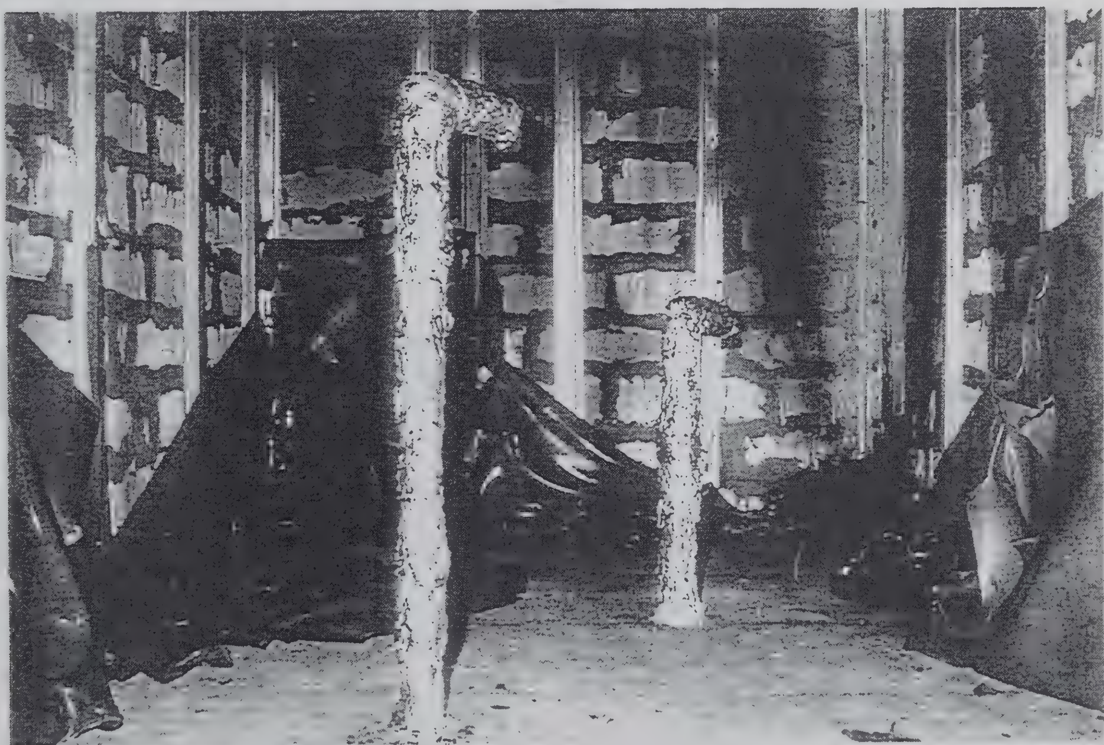
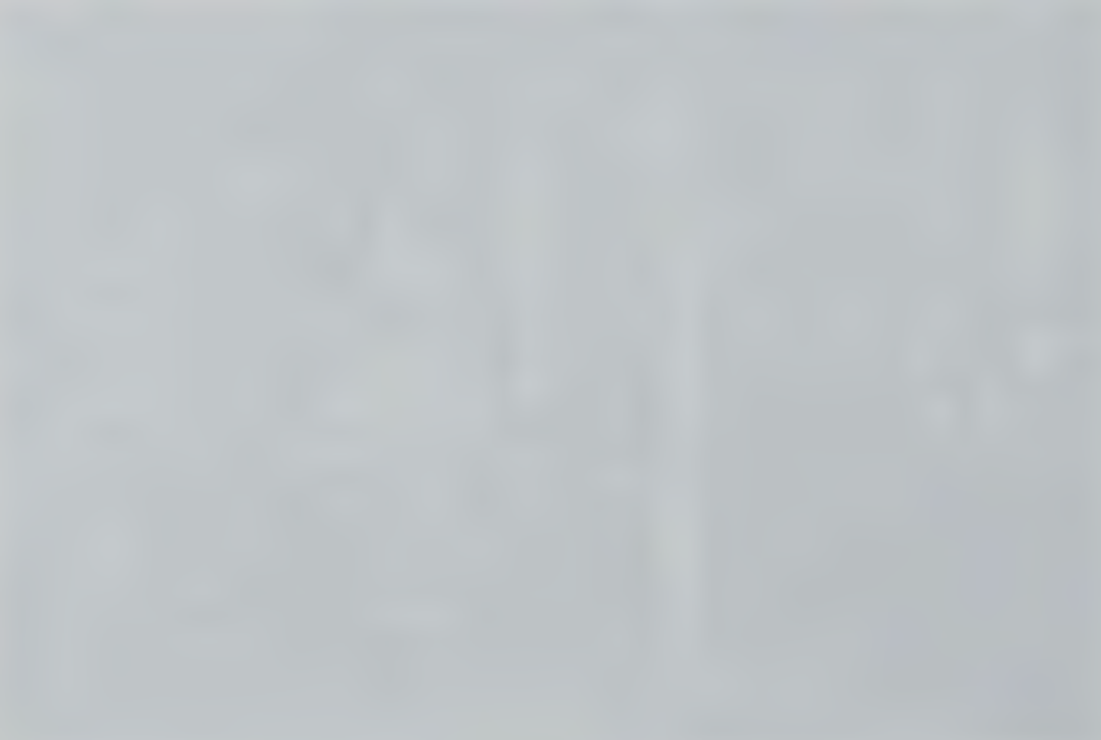


Photo no 6 After test "FR PVC"

Not much material had been consumed. The ceiling panels and most wall panels had melted or just softened and were laying on the floor.



Test results, ISO 9705 (NT FIRE 025)

Product

Acrylic glazing

Mounting

The acrylic glazing panels were screwed to a frame of light steel profiles which gave a spacing of 40 mm to the light weight concrete walls and ceiling.

Observations during test.

Time, [min:s]	Observations
0:00	Ignition of the burner, 100 kW.
1:00	The panels in the burner corner were ignited, see photo no. 2.
1:20	Melted material started to form a pool fire near the burner.
1:30	The ceiling above the burner had ignited, see photo no. 3.
1:45	Several burning droplets were formed.
2:10	Approximately 2 m^2 of melted acrylic was burning on the floor. Limited smoke production.
2:39	Flames out the doorway.
3:00	Extinguishment.
After test:	Most material was burnt or melted. The melted material covered approximately 50% of the floor.

Comments to the graphs

After two minutes the ceiling thermocuple "c1" (closest to the burner) was not anymore in contact with the ceiling material due to the melting of the material and hence "c1" measured only gas temperature from that point in time.

Measured data

Thickness, mm	3
Density, kg/m^3	1150

Conditioning

Temperature 20 ± 5 °C

Test results, graphs

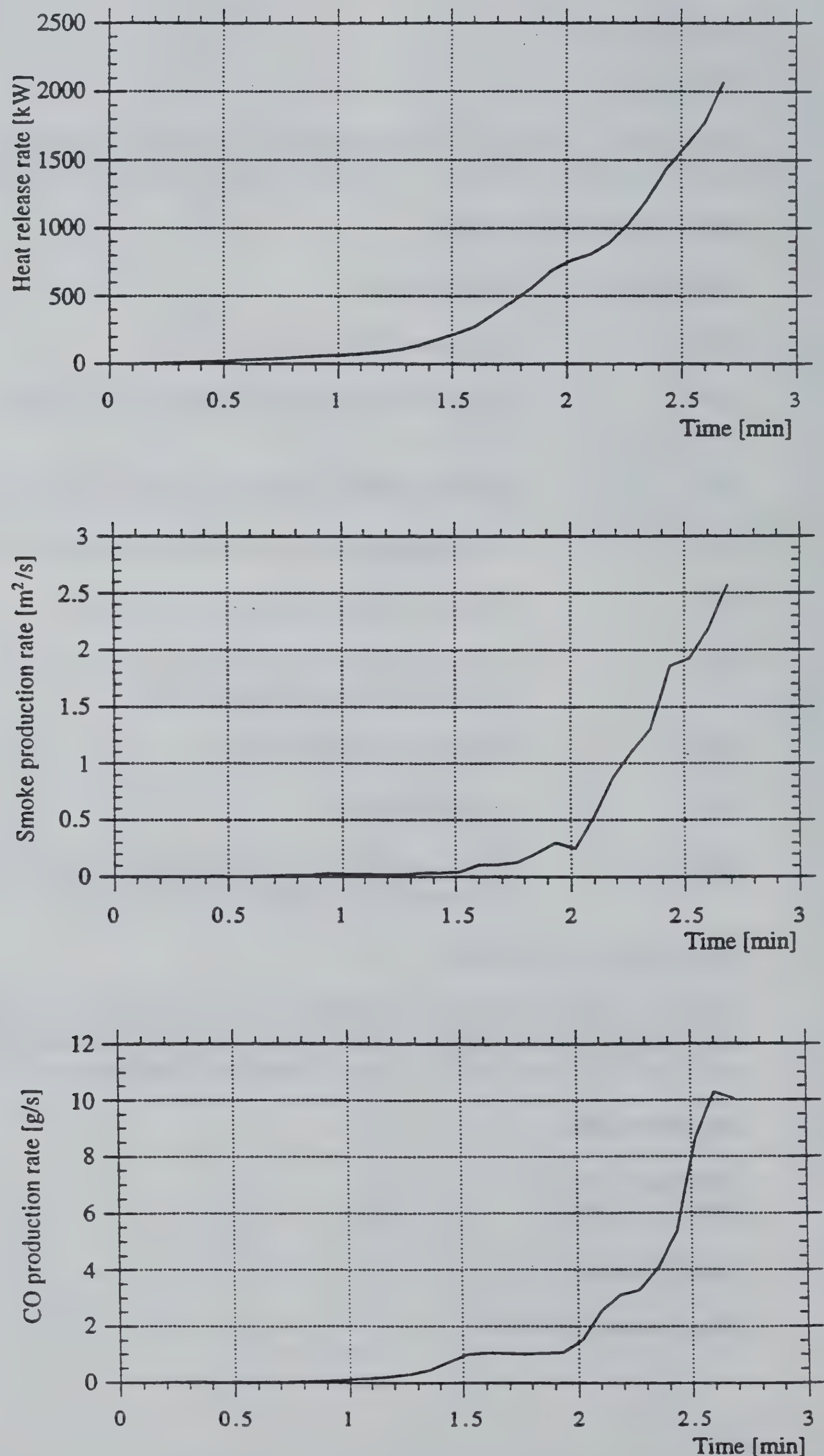


Figure 1 Acrylic glazing, heat release rate (including the HRR from the ignition source), smoke production rate and carbon monoxide production rate

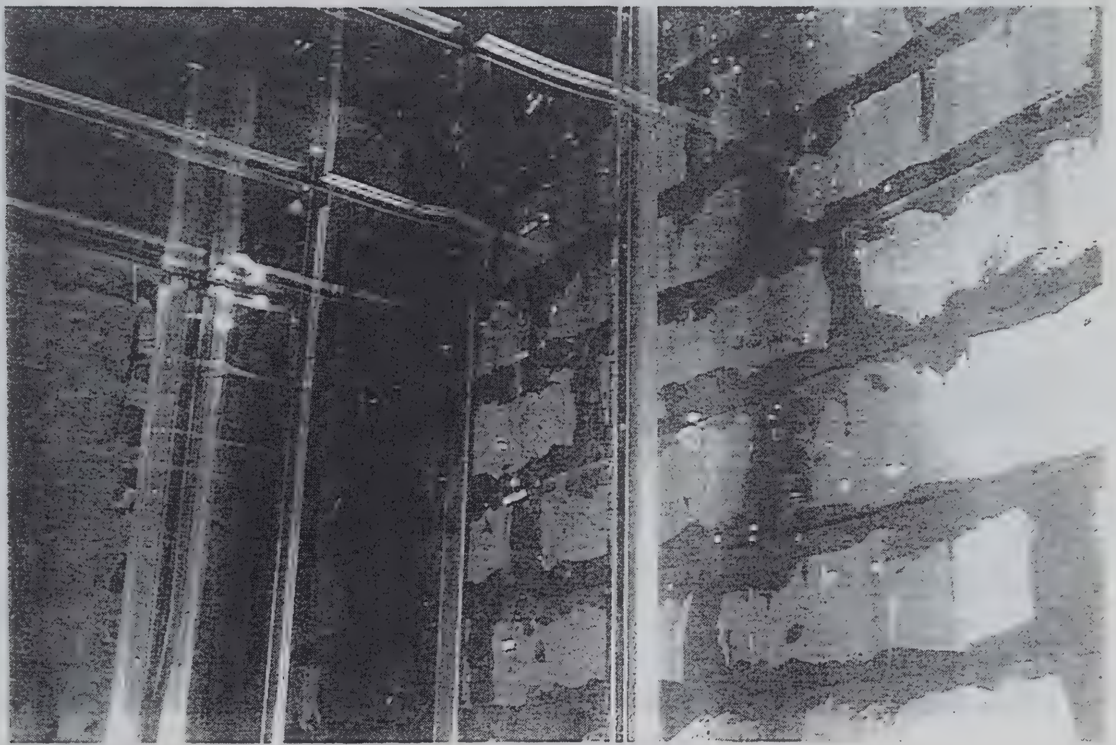


Photo no 1 Prior to test "Acrylic glazing"

The acrylic glazing panels were screwed to a frame of light steel profiles which provided for a spacing of 40 mm to the light weight concrete walls and ceiling.

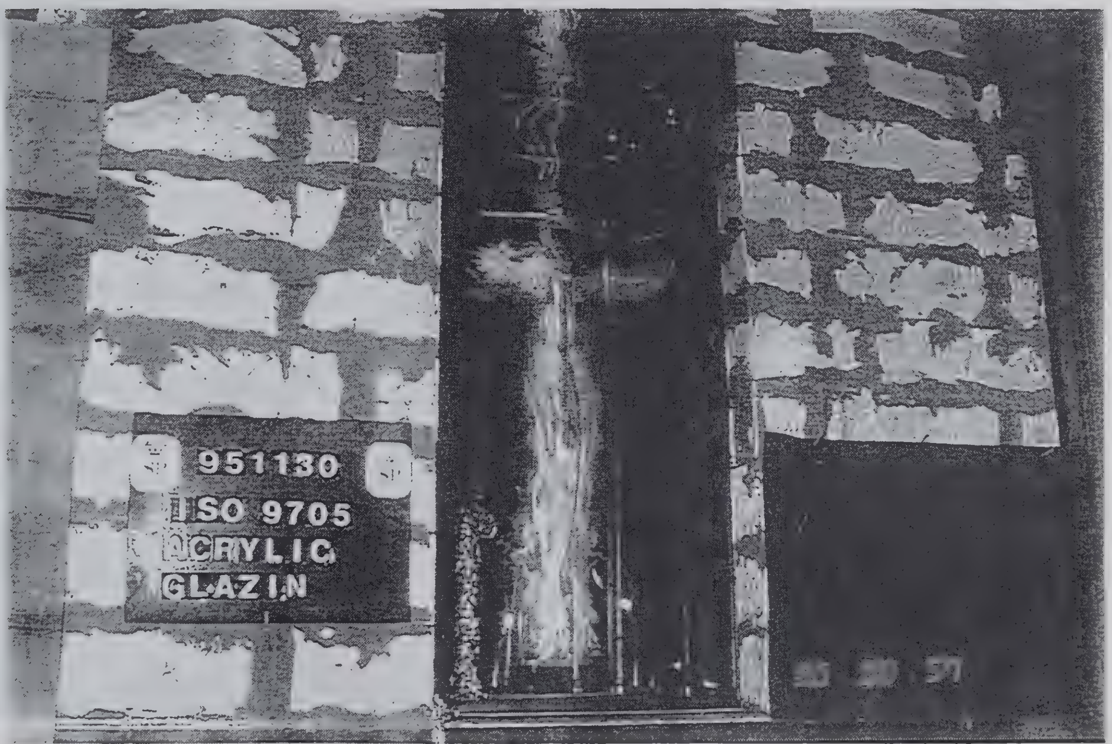


Photo no 2 Time 0:57 "Acrylic glazing"

The panels in the burner corner had ignited.

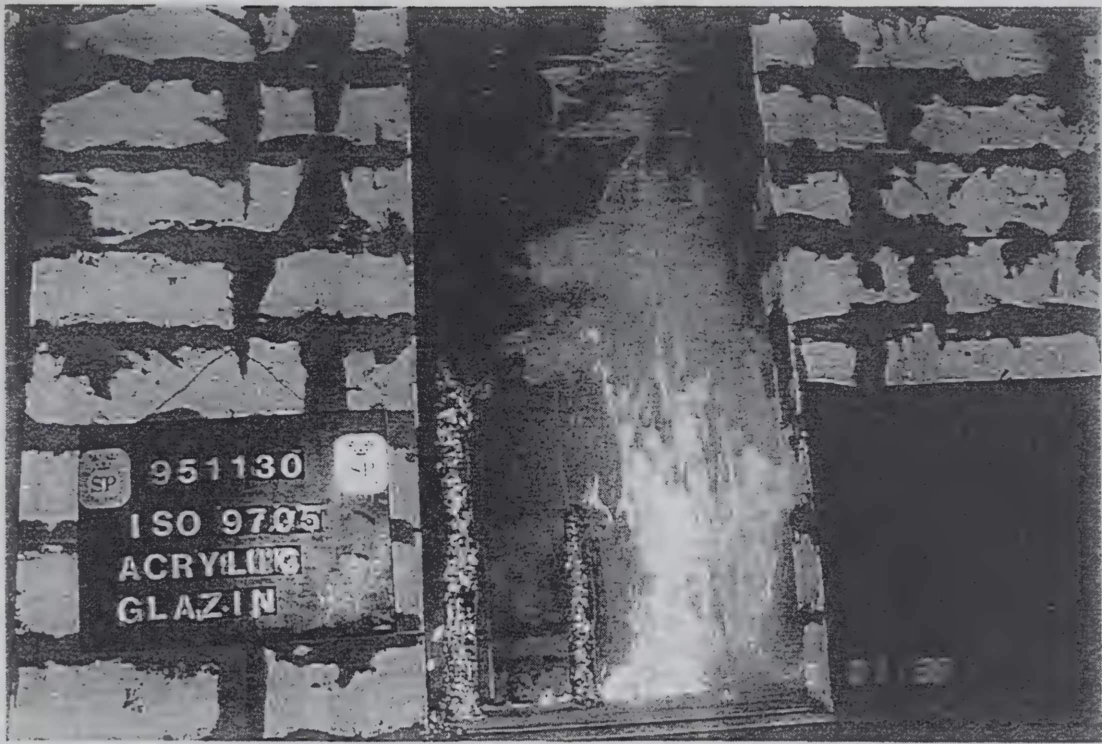


Photo no 3 Time 1:38 "Acrylic glazing"

The ceiling above the burner had ignited. A pool fire was formed.

Photo no 4 Time 2:03 "Acrylic glazing"

Several burning droplets were formed. Approximately 2 m^2 of melted acrylic was burning on the floor. Limited smoke production. Large portions of the walls and the ceiling had already been deformed.

Photo no 5 Time 2:27 "Acrylic glazing"

Flash over was reached. HRR increased. SPR was limited. Burning ceiling material was falling down on the floor.

Photo no 6 After test "Acrylic glazing"

Large portions of melted acrylic had melted and run down on the floor.

Test results, ISO 9705 (NT FIRE 025)

Product

FR extruded polystyrene board, 40 mm

Mounting

The polystyrene boards were glued to a non combustible board called "Promatek H", density 870 kg/m^3, with a water based contact adhesive called "Casco 3880". The non combustible boards were nailed to the light weight concrete walls and ceiling before the polystyrene boards were glued.

Observations during test.

Time, [min:s]	Observations
0:00	Ignition of the burner, 100 kW.
0:20	The material was ignited, see photo no. 2.
0:50	SPR increased, the ceiling was no longer visible, see photo no. 3.
1:25	HRR and SPR started to increase rapidly, see photo no. 4. The ceiling material melted. Burning droplets were formed.
1:40	HRR peaked above 1000 kW, high SPR, see photo no. 5.
2:00	HRR and SPR decreased.
3:30	Only flames in the burner corner.
8:00	Melted polystyrene formed a pool fire near the burner.
10:00	The burner output was increased to 300 kW.
10:10	HRR and SPR increased rapidly.
10:20	Flame spread down the walls, flames out the doorway. Burning droplets were formed, see photo no. 6.
10:40	Gas shut off, extinguishment.
After test:	Most material was burned or melted, see photo no 8.

Measured data

Thickness, mm	40
Density, kg/m^3	33

Conditioning

Temperature 20 ± 5 °C

Test results, graphs

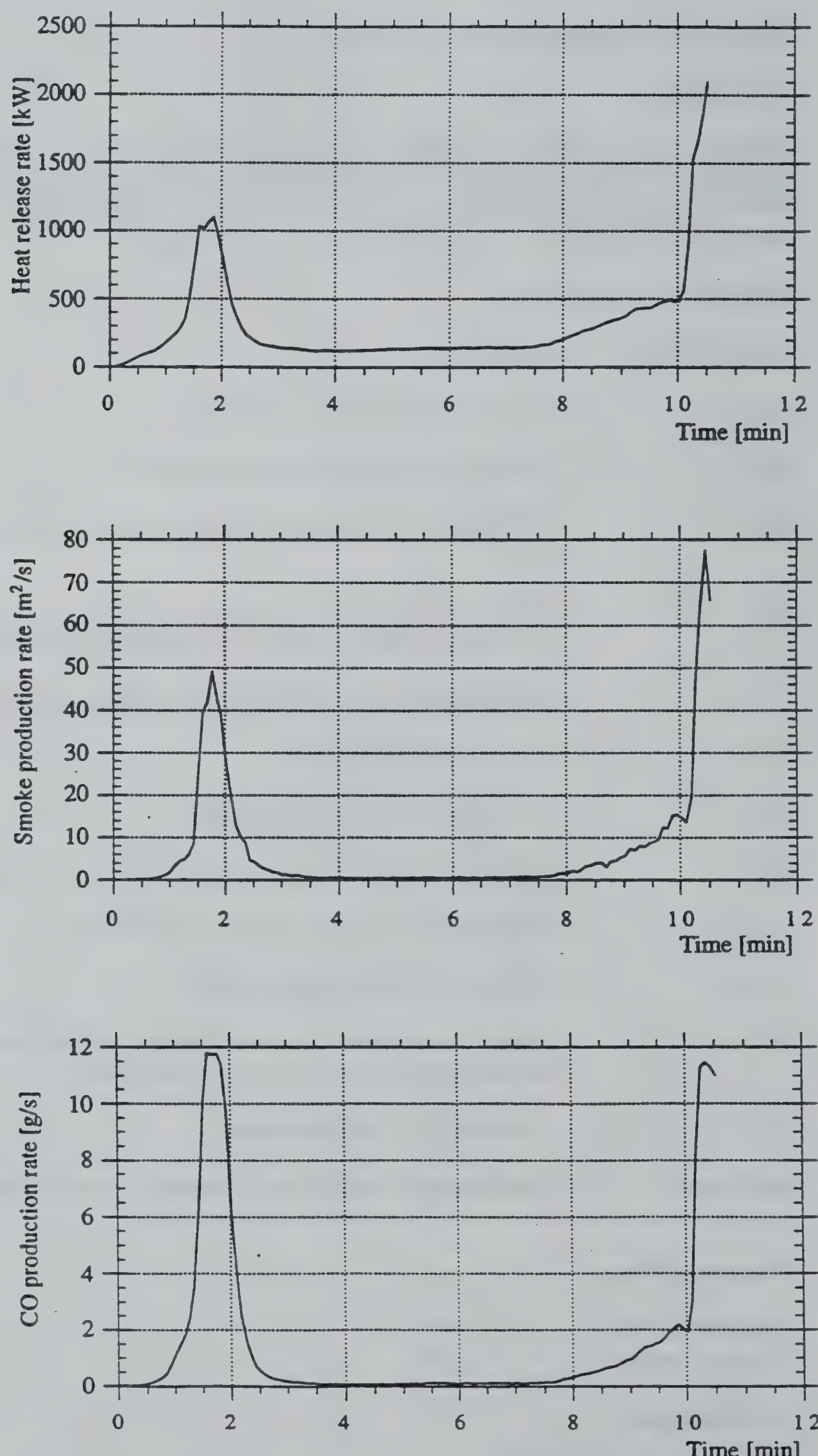


Figure 1 FR extruded polystyrene board, heat release rate (including the HRR from the ignition source), smoke production rate and carbon monoxide production rate

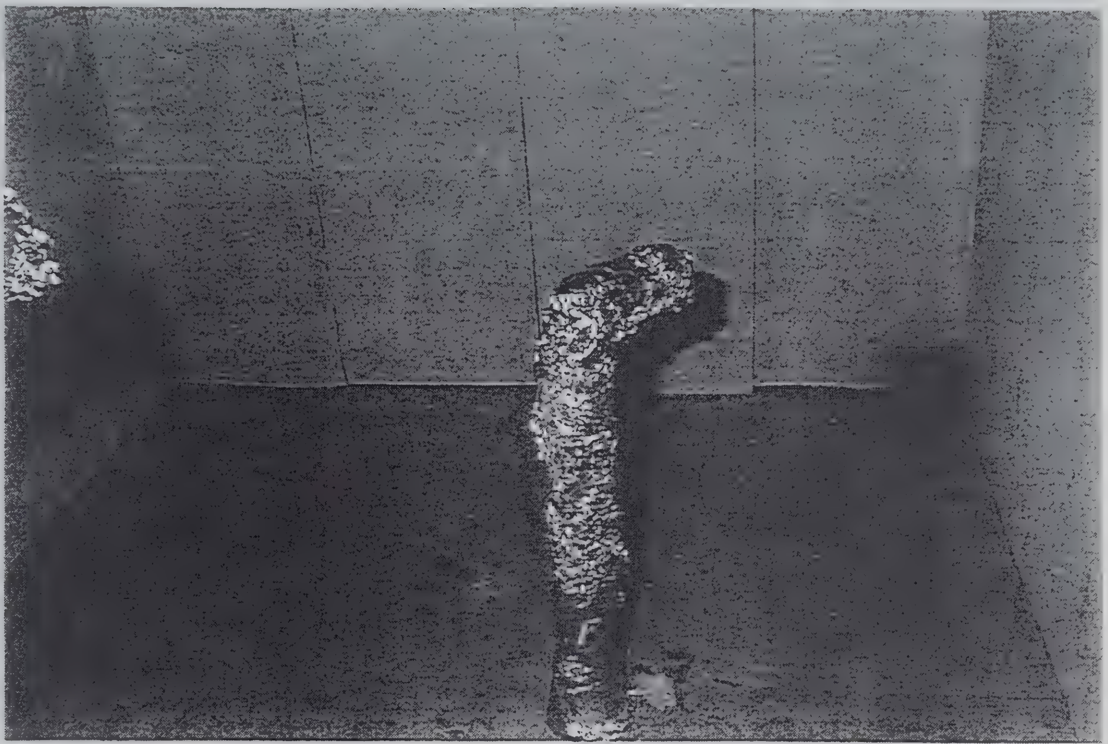


Photo no 1 Prior to test "FR extruded polystyrene board, 40 mm"

The polystyrene boards were glued to a non combustible board. The non combustible boards were nailed to the light weight concrete walls and ceiling.

Photo no 2 Time 0:21 "FR extruded polystyrene board, 40 mm"

The material had ignited.

Photo no 3 Time 0:57 "FR extruded polystyrene board, 40 mm"

SPR increased, the ceiling was no longer visible.

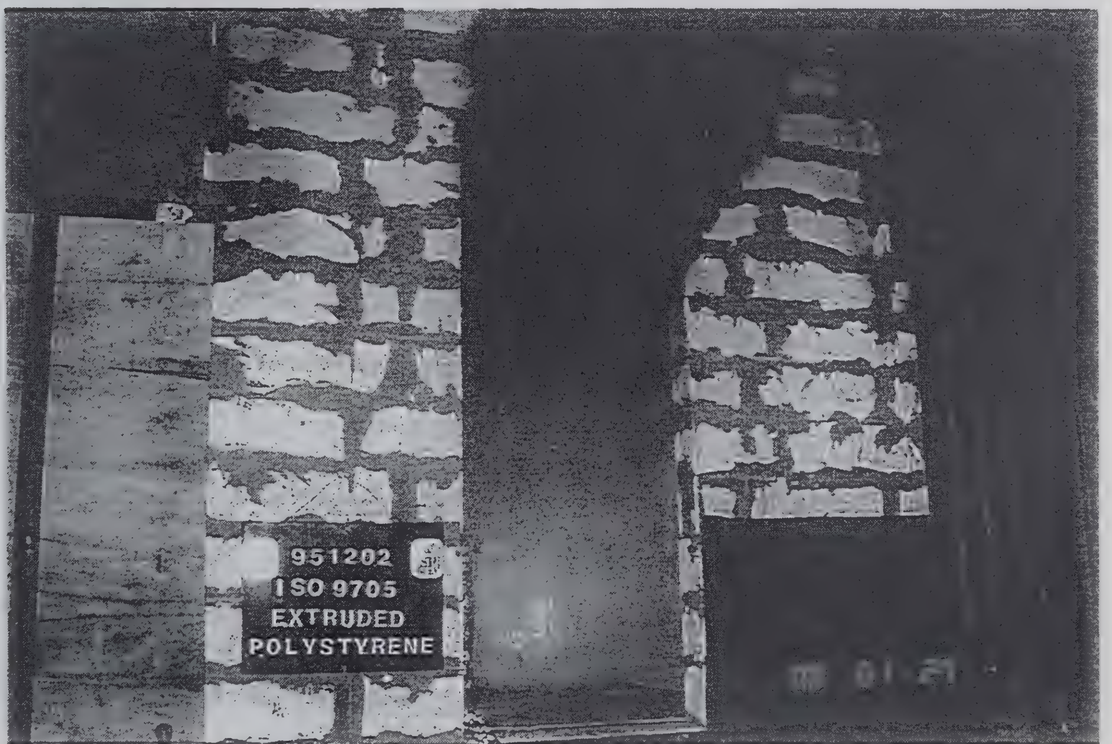


Photo no 4 Time 1:27 "FR extruded polystyrene board, 40 mm"

HRR and SPR started to increase rapidly. The ceiling material melted. Burning droplets were formed.

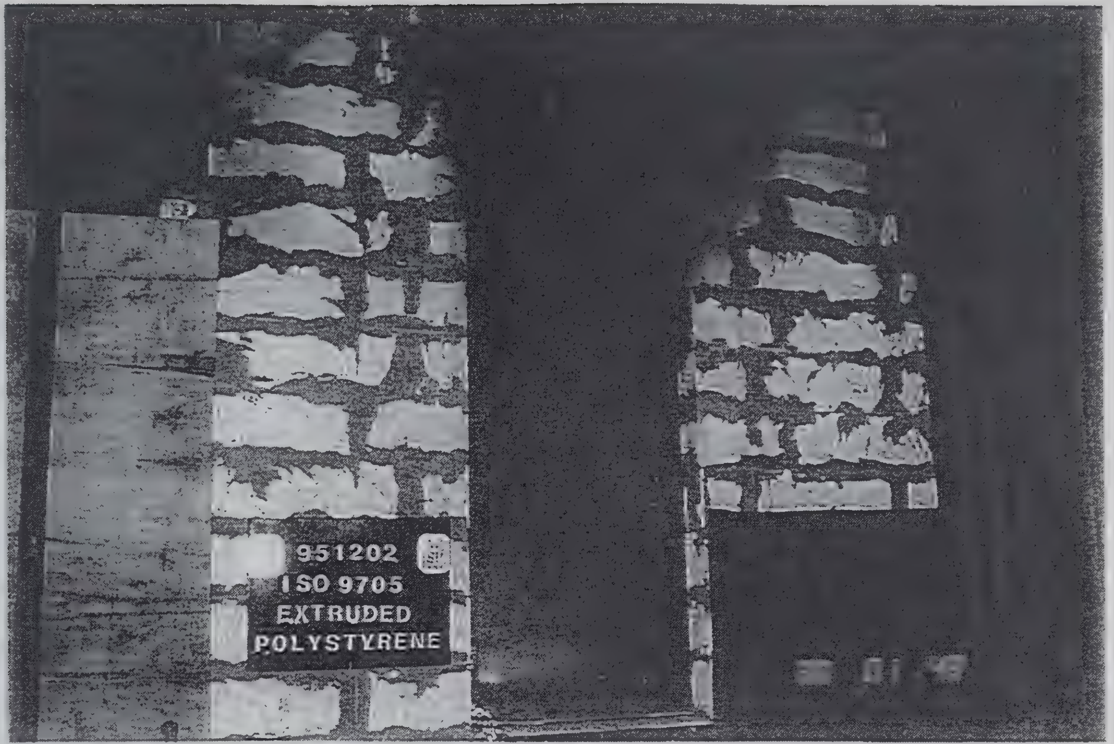


Photo no 5 Time 1:42 "FR extruded polystyrene board, 40 mm"

HRR peaked above 1000 kW, high SPR.

Photo no 6 Time 10:23 "FR extruded polystyrene board, 40 mm"

Flash over was reached. HRR and SPR increased rapidly. Flame spread downward the walls, flames out the doorway. Burning droplets were formed.

Photo no 7 Time 10:32 "FR extruded polystyrene board, 40 mm"

HRR peaked above 2 MW. The entire room was engulfed in flames. Excessive SPR.

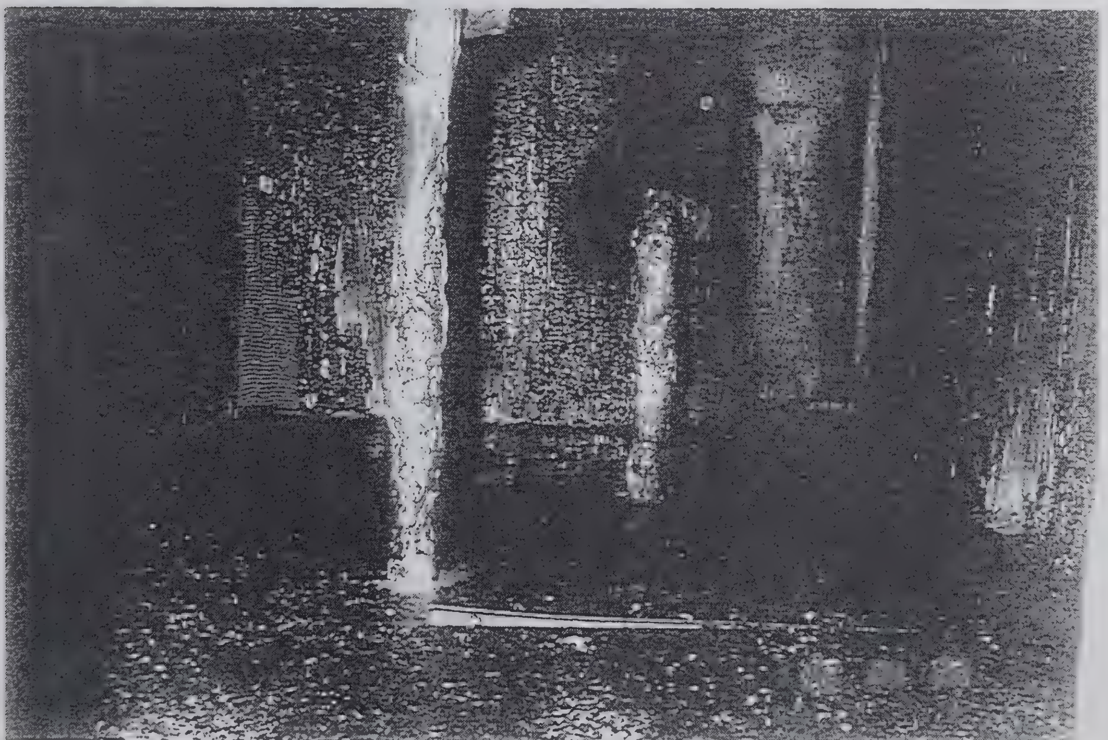


Photo no 8 After test "FR extruded polystyrene board, 40 mm"

Most material was burnt or melted. The entire floor was covered with melted polystyrene.

Test results, ISO 9705 (NT FIRE 025)

Product

PUR foam panel with al faced paper finish.

Mounting

The PUR foam panels were glued to a non combustible board called "Promatek H", density 870 kg/m^3, with a water based contact adhesive called "Casco 3880". The non combustible boards were nailed to the light weight concrete walls and ceiling before the PUR foam panels were glued.

Observations during test.

Time, [min:s]	Observations
0:00	Ignition of the burner, 100 kW.
0:14	The aluminium surface started to get damaged in the burner corner, see photo no. 2.
0:25	Smoke production started. Large portions of the ceiling were ignited, see photo no. 3.
0:38	Flames out the doorway. High SPR was seen. Flame spread down the walls, see photo no. 4.
0:40	HRR reached 2 MW.
1:00	Gas shut off, extinguishment.
After test:	The entire ceiling was charred but not totally consumed. Large portions of the aluminium paper surface were still intact on the walls, see photo no 6.

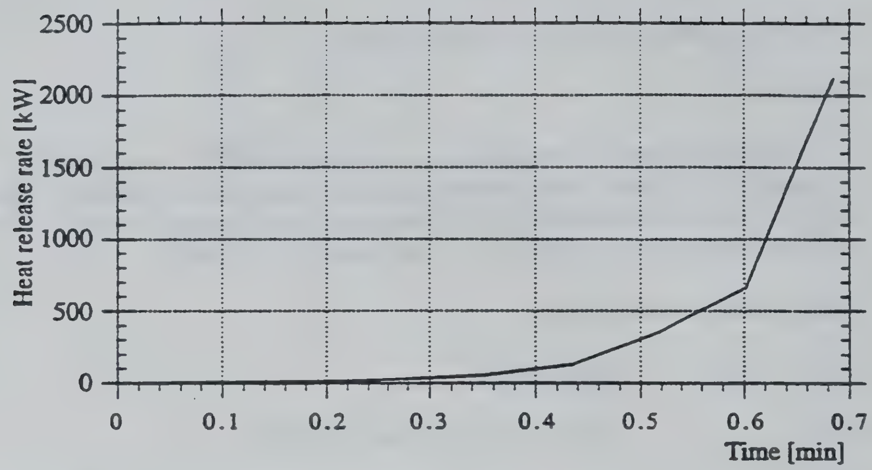
Measured data

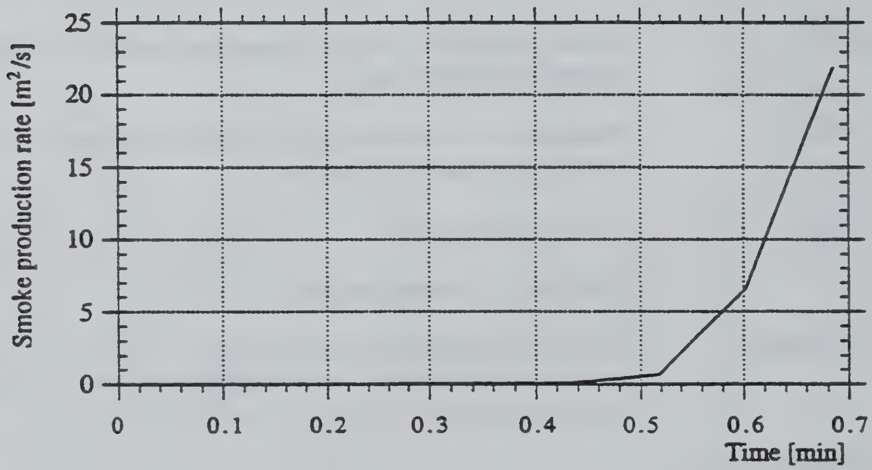
Thickness, mm	41
Area weight, kg/m^2	2.03
Density, kg/m^3	38 (PUR)

Conditioning

Temperature 20 ± 5 °C

Test results, graphs





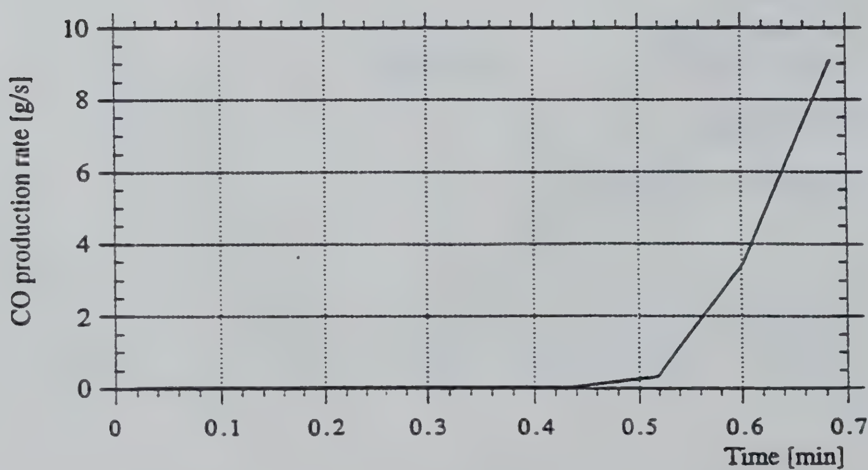


Figure 1 PUR foam panel with al faced paper finish, heat release rate (including the HRR from the ignition source), smoke production rate and CO production rate.

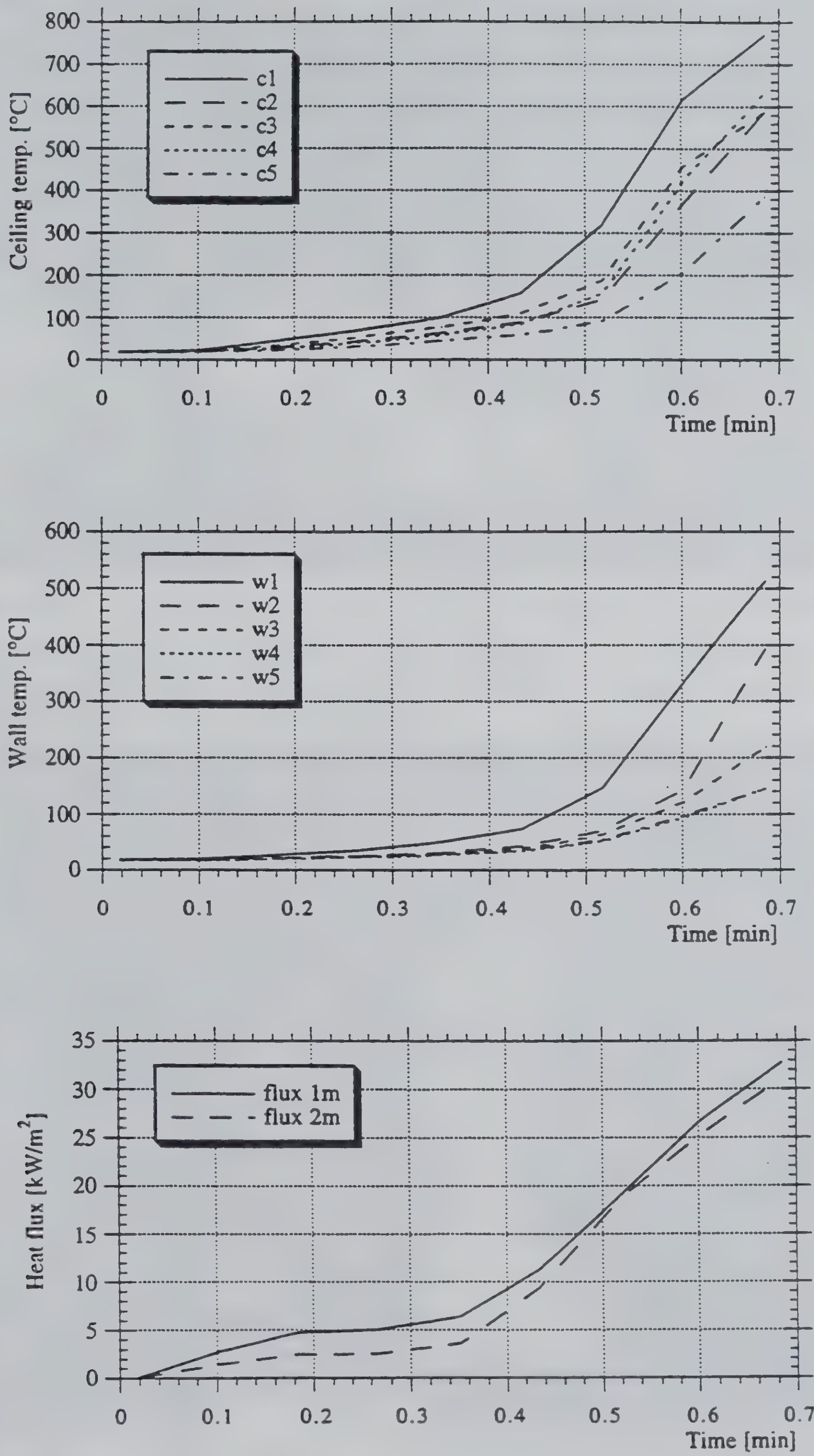


Figure 2 PUR foam panel with al faced paper finish, ceiling temperatures, wall temperatures and heat flux, including the contribution from the ignition source.

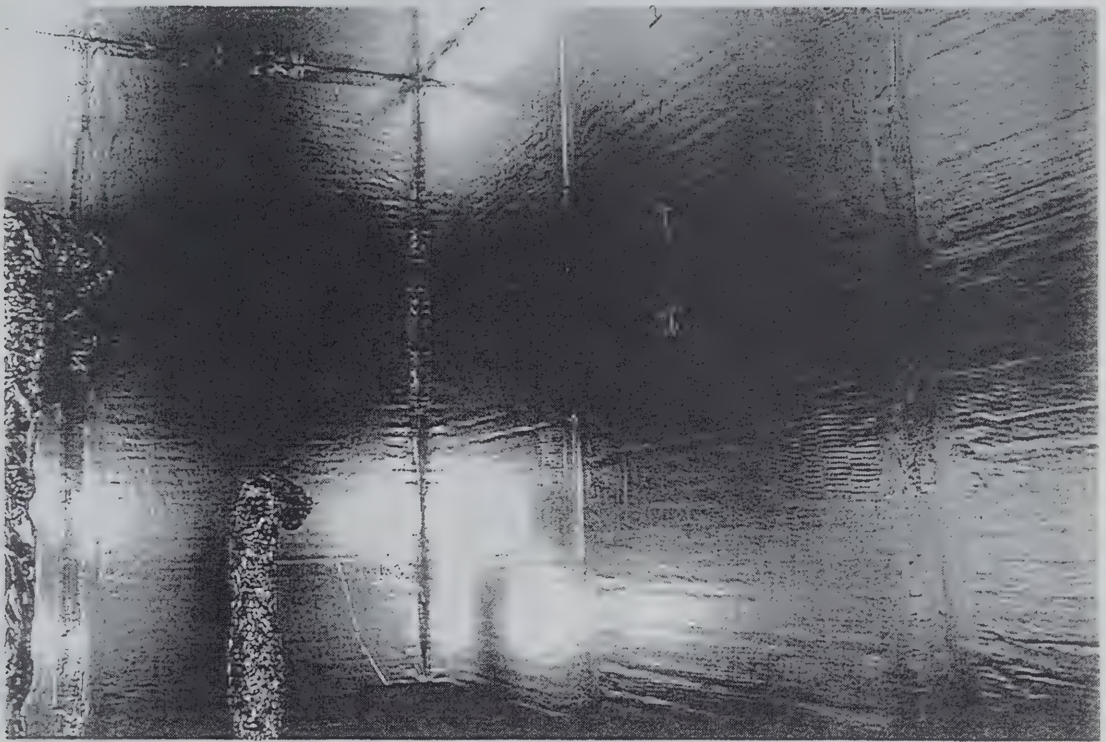


Photo no 1 Prior to test "PUR foam panel with al faced paper"

The PUR foam panels were glued to a non combustible board. The non combustible boards were nailed to the light weight concrete walls and ceiling. The joints between the panels were sealed with aluminium tape.

Photo no 2 Time 0:14 "PUR foam panel with al faced paper"

The aluminium paper surface started to get damaged in the burner corner.

Photo no 3 Time 0:27 "PUR foam panel with al faced paper"

Smoke production started. Large portions of the ceiling were ignited.

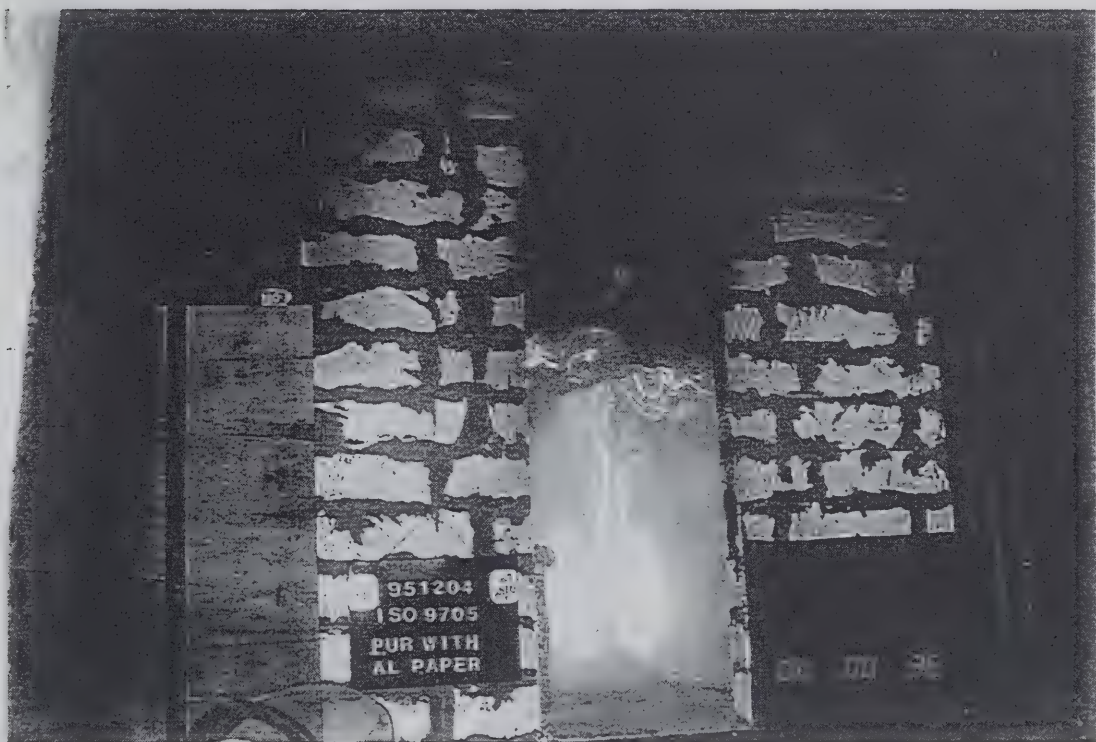


Photo no 4 Time 0:38 "PUR foam panel with al faced paper"

Flames out the doorway. High HRR and SPR was seen. Flame spread downward the walls.

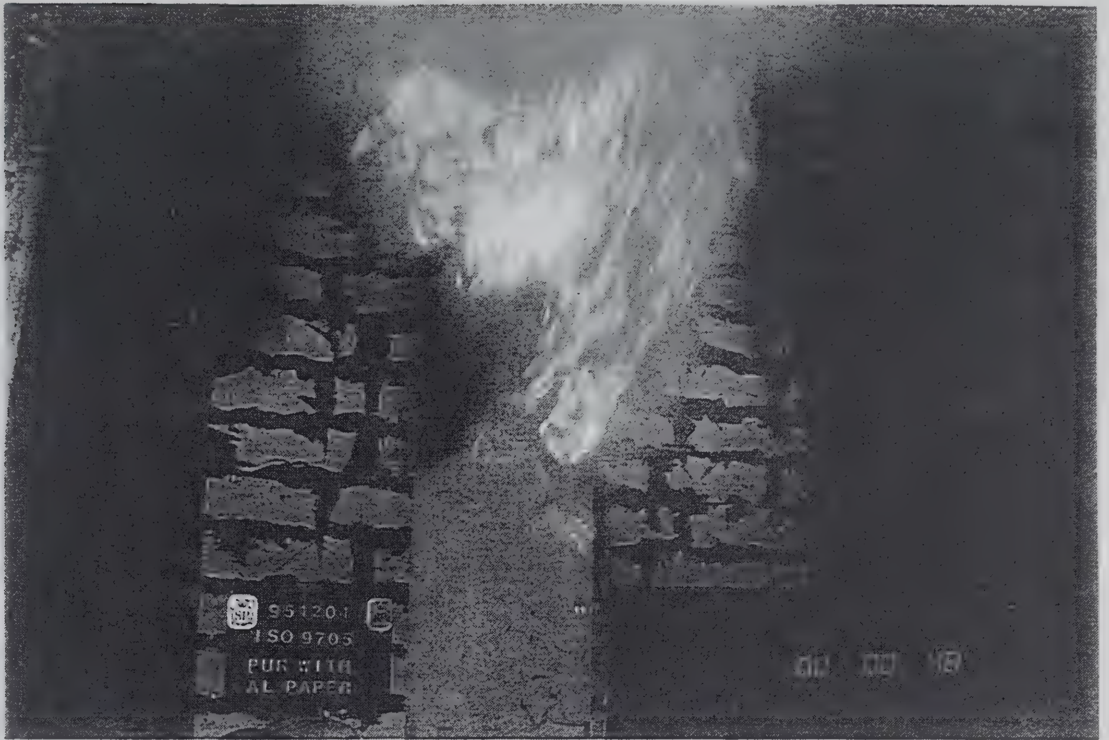


Photo no 5 Time 0:48 "PUR foam panel with al faced paper"

Flash over was reached. Rapid increase in HRR and flame spread. High SPR.

Photo no 6 After test "PUR foam panel with al faced paper"

The entire ceiling was charred but not totally consumed. Large portions of the aluminium paper surface were still intact on the walls.

Test results, ISO 9705 (NT FIRE 025)

Product

Mass timber, varnished

Mounting

The mass timber was nailed to the lightweight concrete walls and ceiling.

Observations during test.

Time, [min:s]	Observations
0:00	Ignition of the burner, 100 kW.
0:25	The lacquer finish had ignited, see photo no. 2.
0:45	The ceiling tiles above the burner had ignited. Low SPR.
1:00	The ceiling was no longer visible due to smoke production, see photo no. 4.
1:30	Downward flame spread was seen on the walls, see photo no. 5 and 6.
1:48	Flames out the doorway, see photo no. 7.
2:10	Half of the height of the walls was engulfed in flames.
2:20	Gas shut off.
2:35	Extinguishment.
After test:	The entire ceiling and slightly more than 50 % of the wall surface were charred. Other parts were discoloured or undamaged.

Comments to the graphs

After approximately one minute the ceiling thermocouple "c2" was not fully in contact with the material anymore. After approximately one minute, the reading of the heat flux meter at 2 m is higher than the reading of the heat flux meter at 1 m, mainly because it captured more flame radiation from the burning timber than the other one.

Measured data

Thickness, mm	9
Area weight, kg/m^2	3.4
Moisture content, %	9.6

Conditioning

Temperature 20 ± 5 °C

Test results, graphs

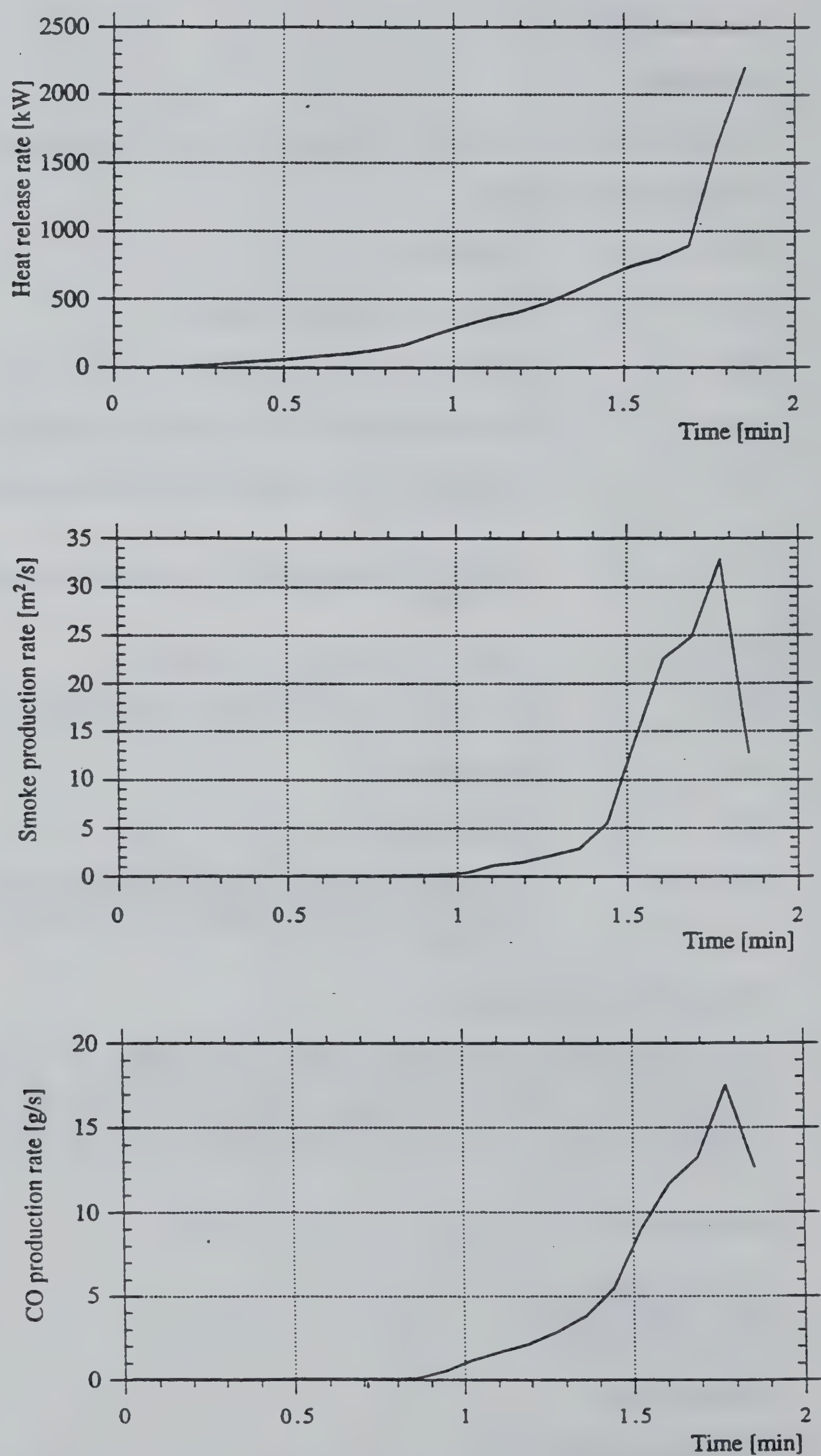


Figure 1 Mass timber (pine) varnished, heat release rate (including the HRR from the ignition source), smoke production rate and carbon monoxide production rate

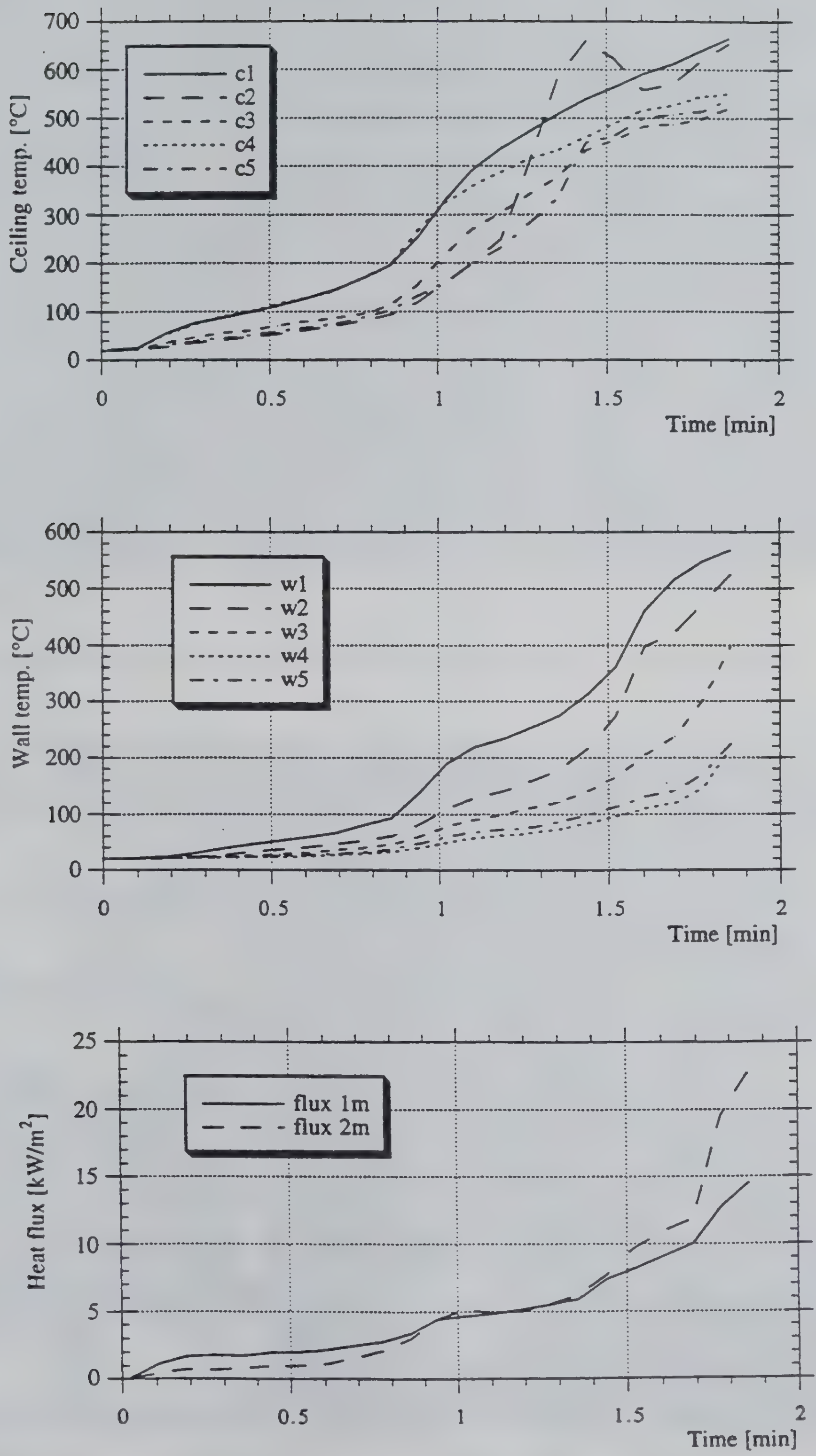


Figure 2 Mass timber (pine) varnished, ceiling temperatures, wall temperatures and heat flux, including the contribution from the ignition source.

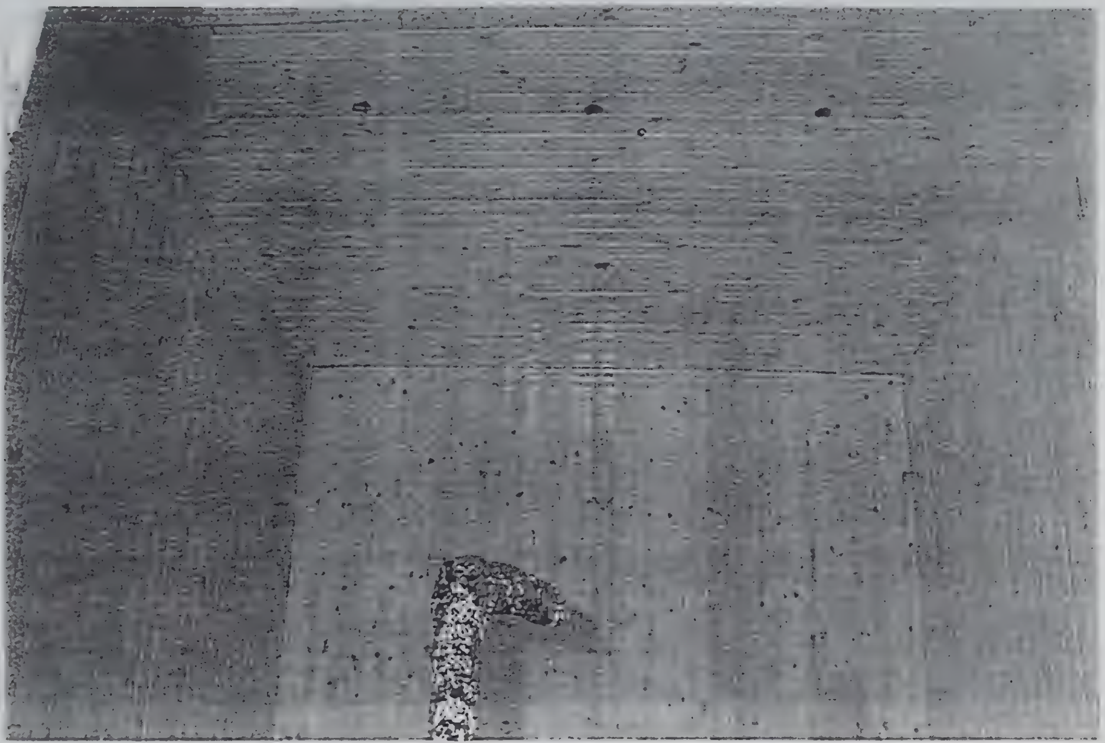


Photo no 1 Prior to test "Mass timber, varnished"

The mass timber was nailed to the lightweight concrete walls and ceiling.

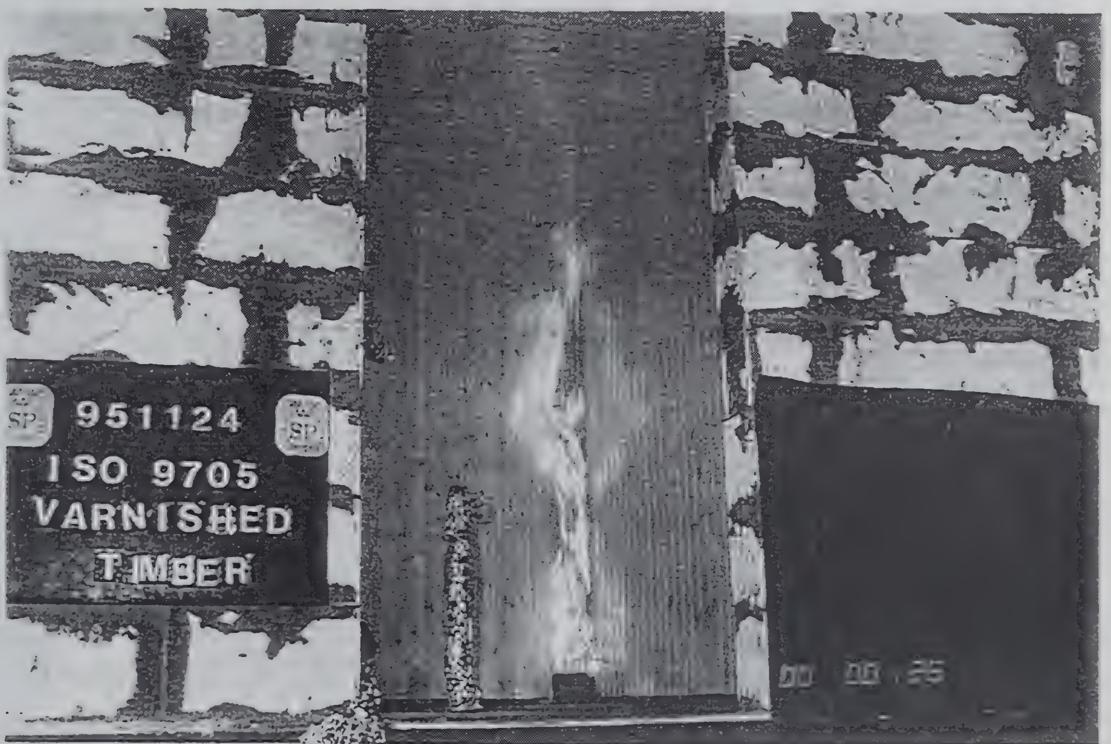


Photo no 2 Time 0:25 "Mass timber, varnished"

The lacquer finish had ignited.

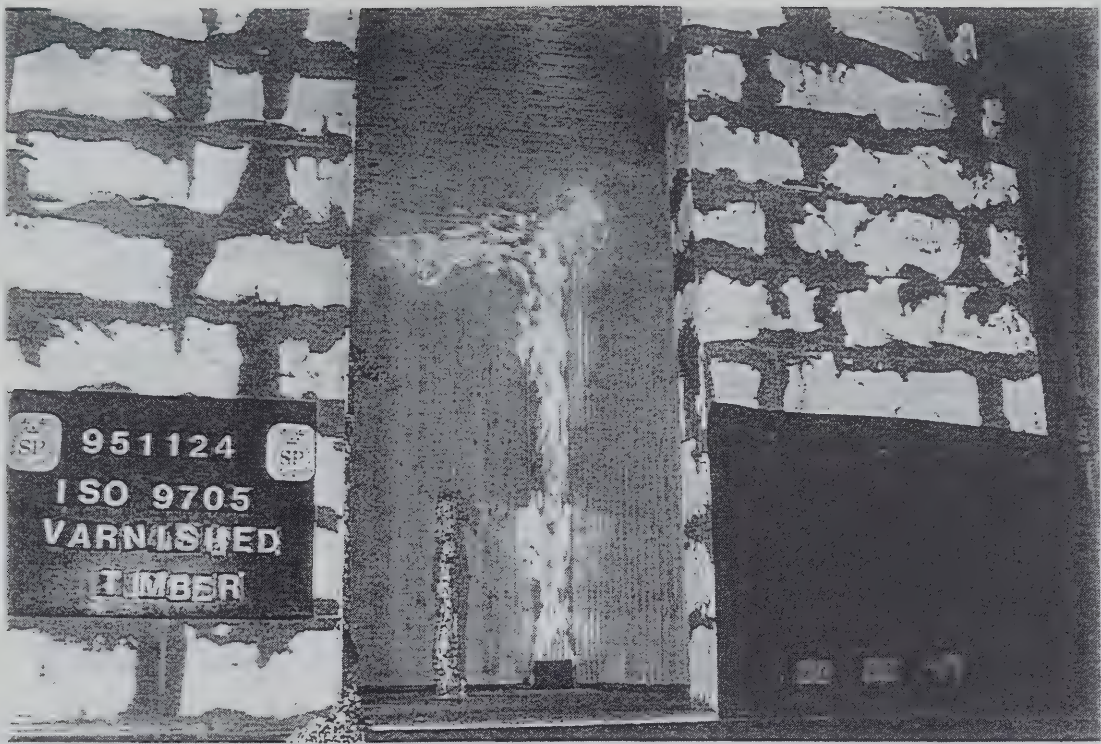


Photo no 3 Time 0:47 "Mass timber, varnished"

Flames had reached and ignited the ceiling timber above the burner. Low SPR.

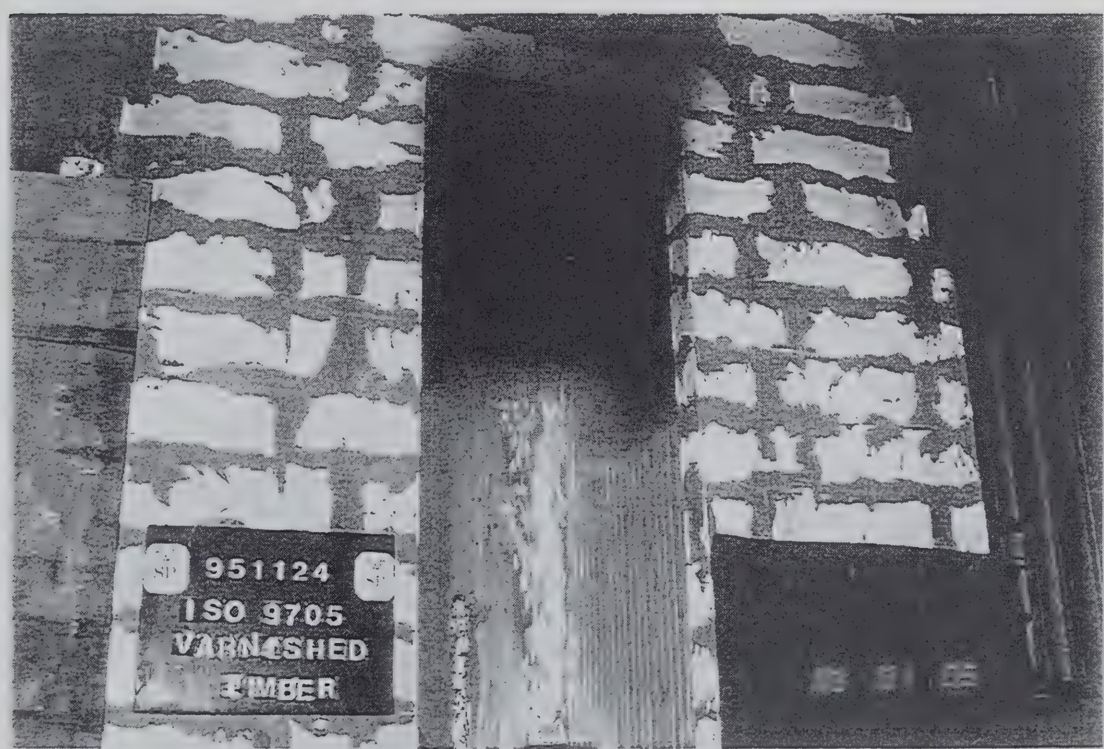


Photo no 4 Time 1:05 "Mass timber, varnished"

SPR had increased. The ceiling was no longer visible.

Photo no 5 Time 1:33 "Mass timber, varnished"

Downward flame spread was seen on the rear wall.

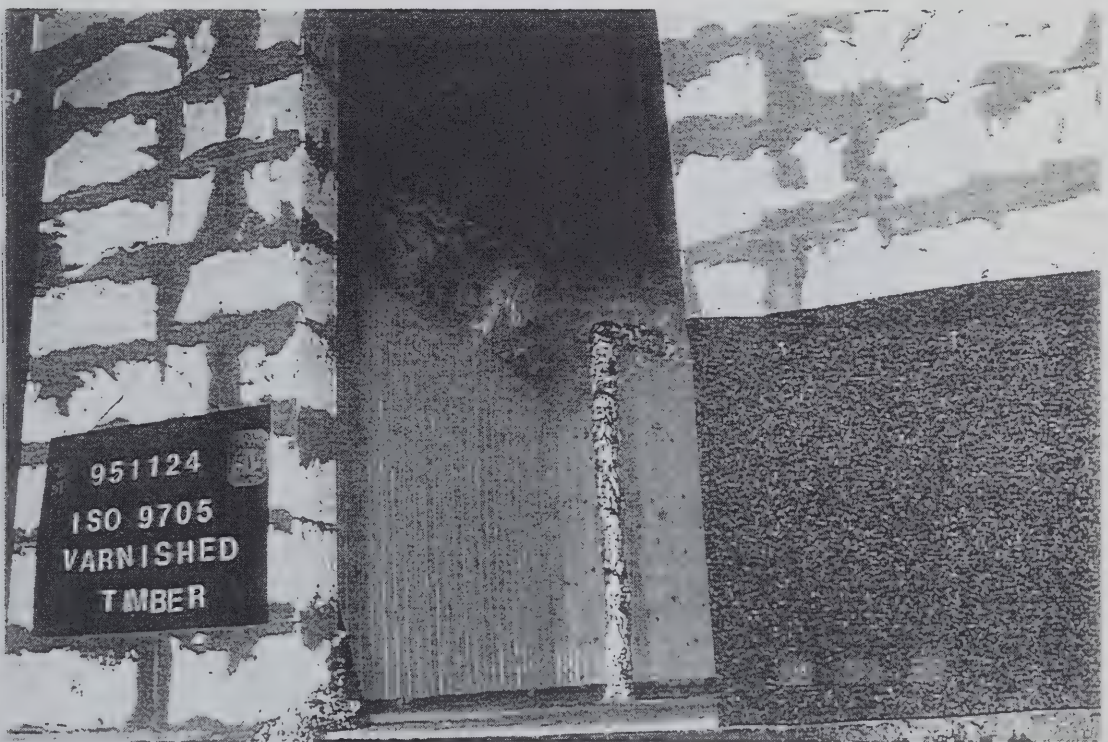


Photo no 6 Time 1:38 "Mass timber, varnished"

Downward flame spread was seen on the left wall. HRR and SPR increased.

Photo no 7 Time 1:49 "Mass timber, varnished"

Flames were seen out the doorway. Flash over was reached.

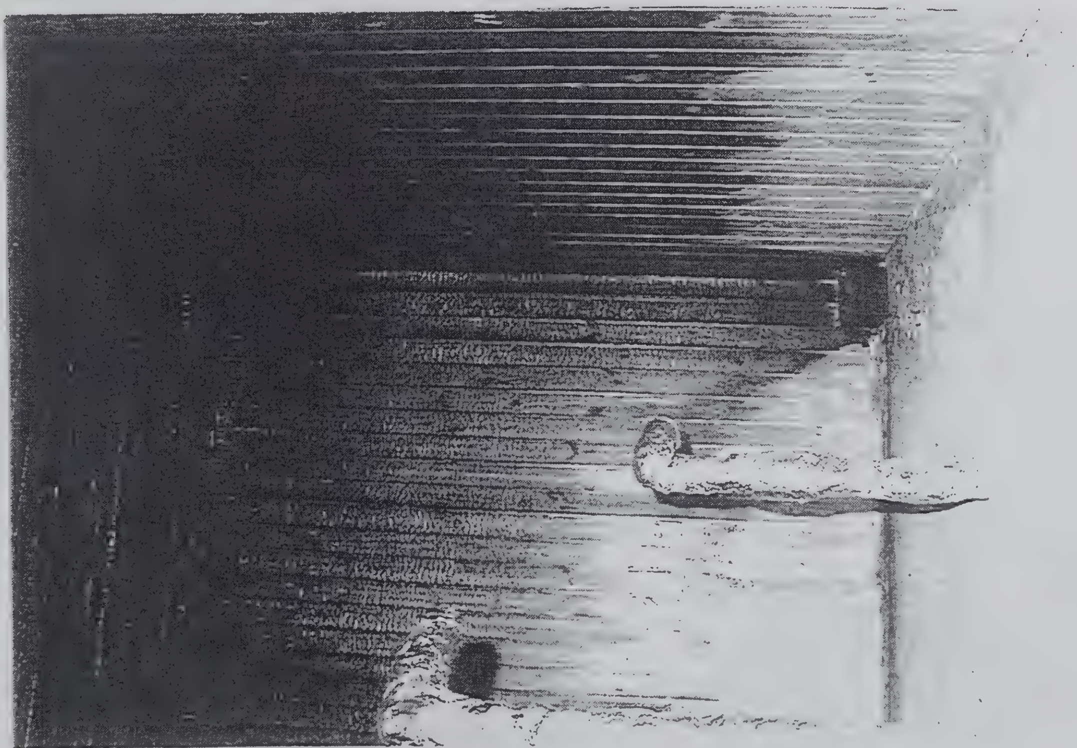


Photo no 8 After test "Mass timber, varnished"

The room fire was extinguished at 2:35 [min:s]. The entire ceiling and slightly more than 50% of the walls were charred.

Test results, ISO 9705 (NT FIRE 025)

Product

FR chipboard

Mounting

The FR chipboard was nailed to the lightweight concrete walls and ceiling.

Observations during test.

Time, [min:s]	Observations
0:00	Ignition of the burner, 100 kW.
2:00	A smoke gas layer was formed, low HRR, see photo no. 2.
5-10:00	Low HRR, no flame spread was seen, see photo no. 3.
10:00	The burner output was increased to 300 kW.
11:00	HRR and SPR increased. The height of the smoke gas layer was approximately 1 meter, see photo no. 4.
15:00	HRR and SPR had reached maximum levels. Flames were seen in the inner half of the ceiling. Limited flame spread on the walls, see photo no. 5
20:00	Gas shut off.
After test:	Afterglow was seen in the material at the burner corner. The glowing combustion was extinguished 17 minutes after gas shut off. The ceiling was partly charred. Most parts of the walls were only discoloured.

Measured data

Thickness, mm	12.2
Density, kg/m^3	805
Moisture content, %	6.8

Conditioning

Temperature 20 ± 5 °C

Test results, graphs

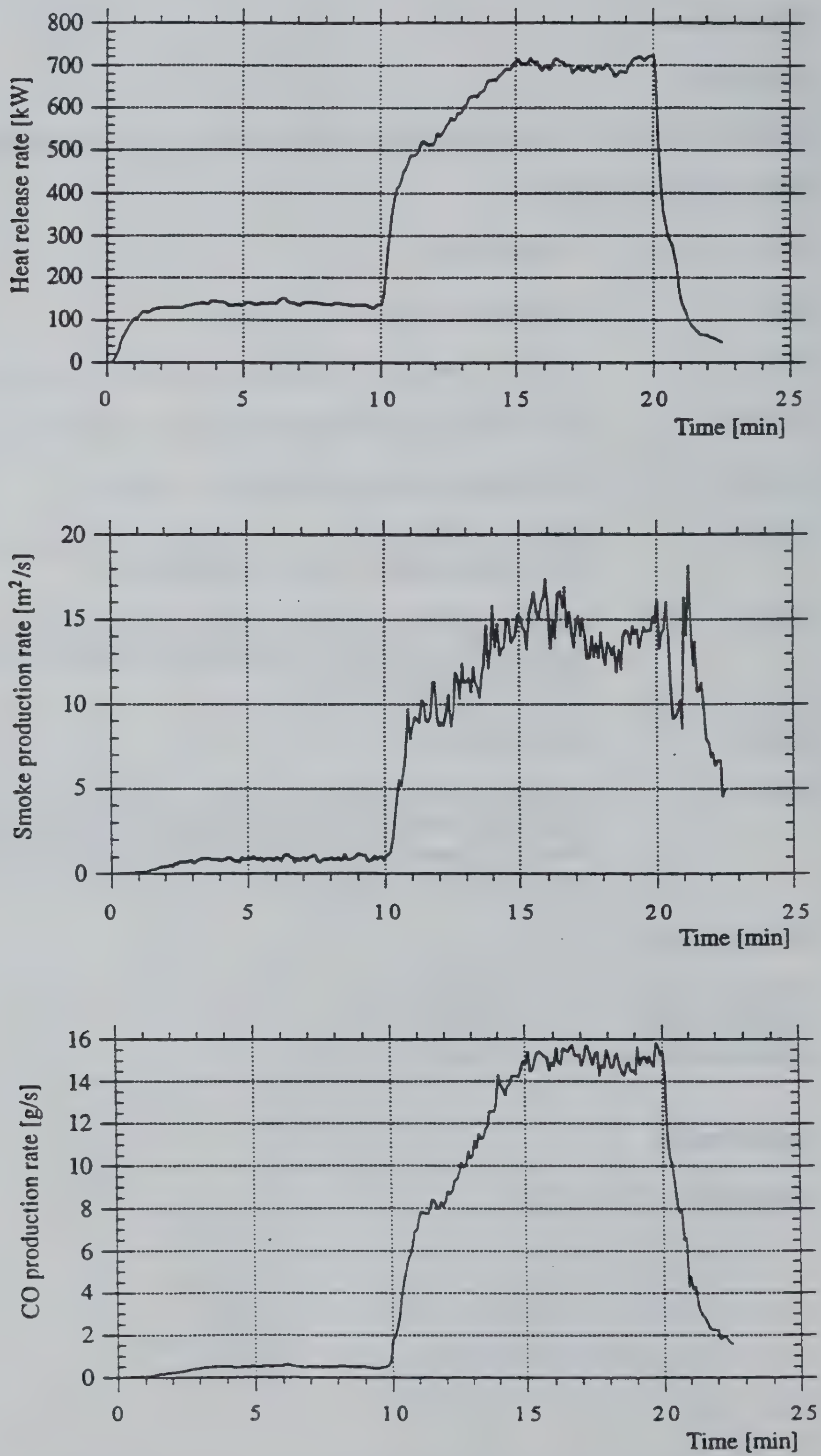


Figure 1 FR chipboard, heat release rate (including the HRR from the ignition source), smoke production rate and carbon monoxide production rate

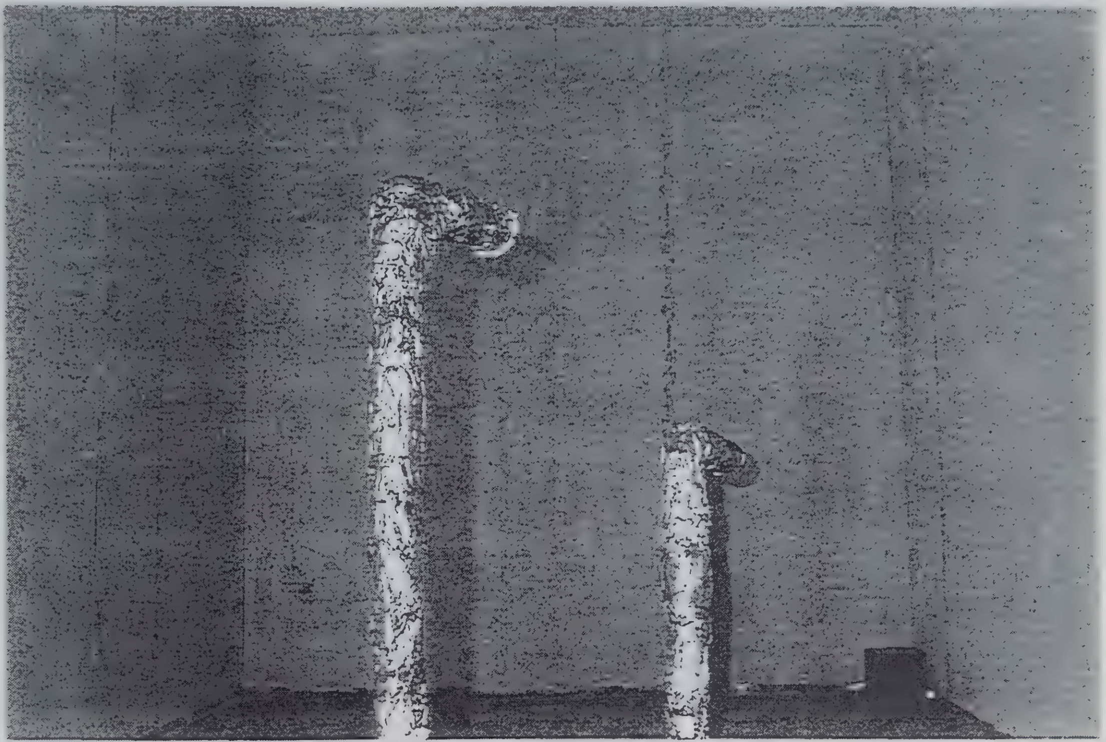


Photo no 1 Prior to test "FR chipboard"

The FR chipboard were nailed to the lightweight concrete walls and ceiling.

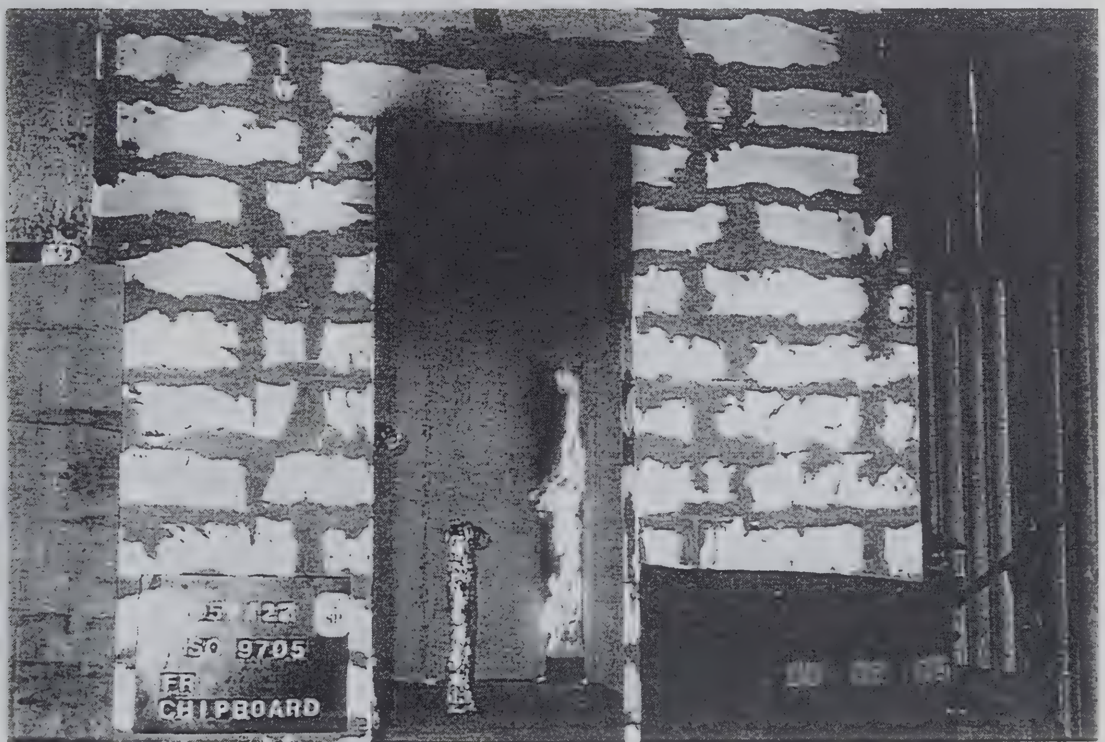


Photo no 2 Time 2:05 "FR chipboard"

A smoke gas layer was formed, low HRR.

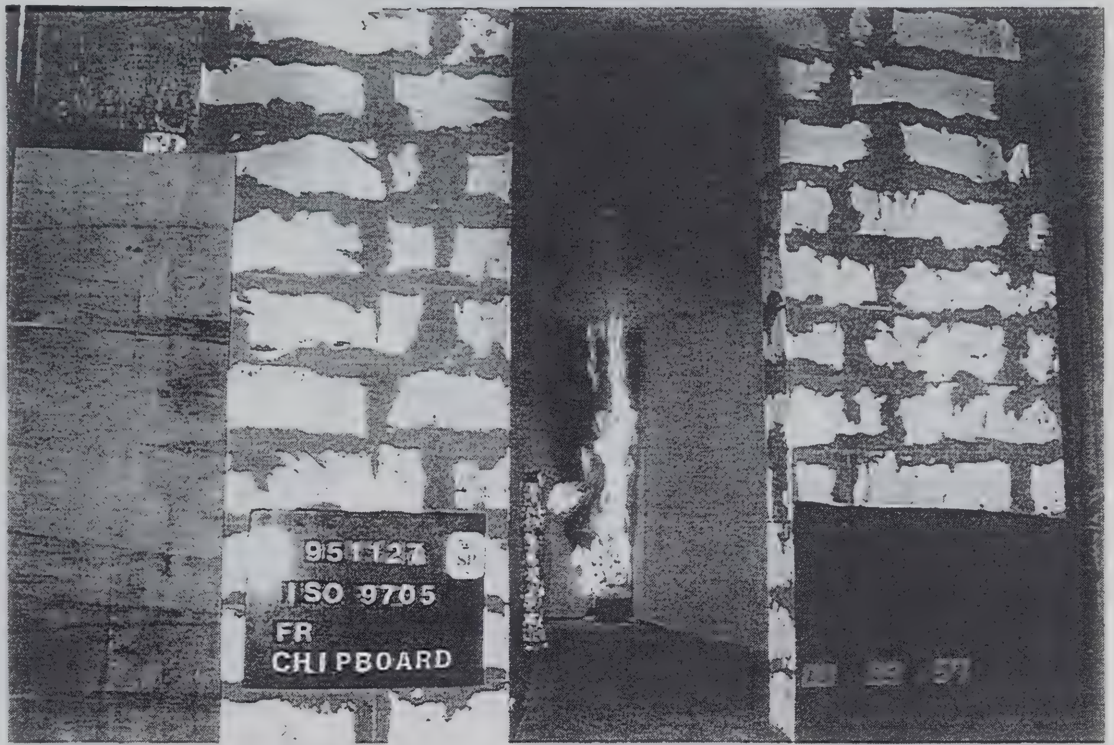


Photo no 3 Time 9:57 "FR chipboard"

Low HRR, no flame spread was seen. Some flames were seen in the material in the vicinity of the burner.

Photo no 4 Time 10:47 "FR chipboard"

The burner heat output had been increased to 300 kW. HRR and SPR increased. The height of the smoke gas layer was approximately 1 meter below the ceiling.

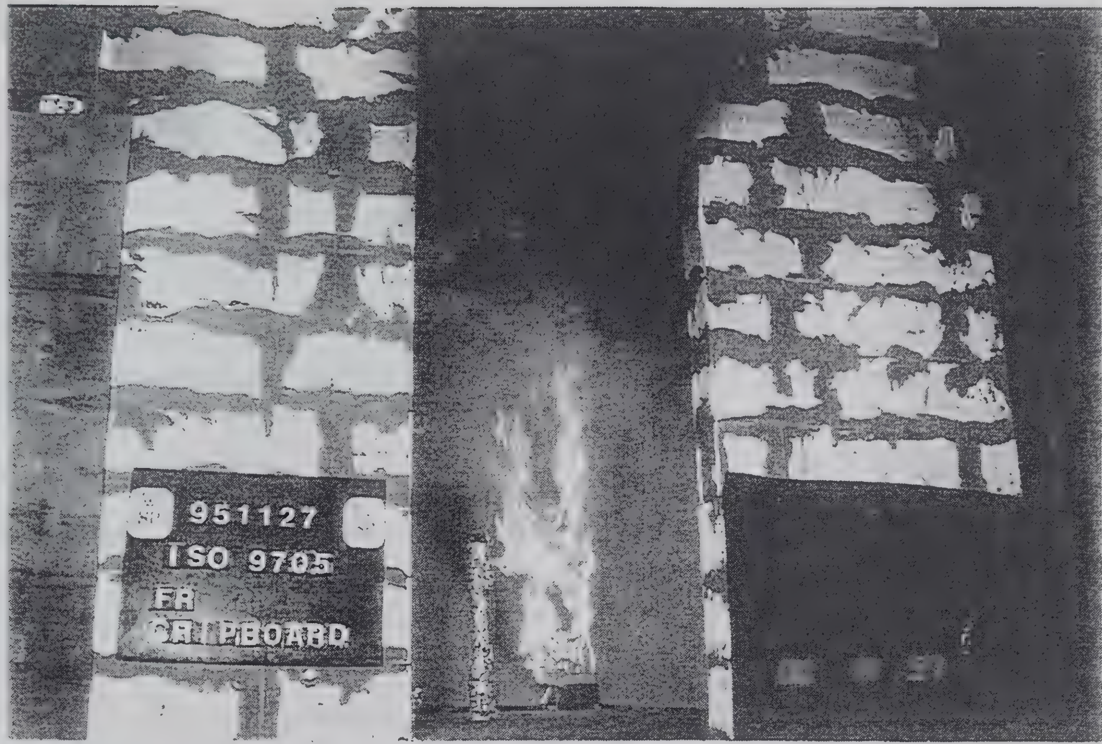


Photo no 5 Time 14:57 "FR chipboard"

HRR and SPR had reached maximum levels. Flames were seen in the inner half of the ceiling.

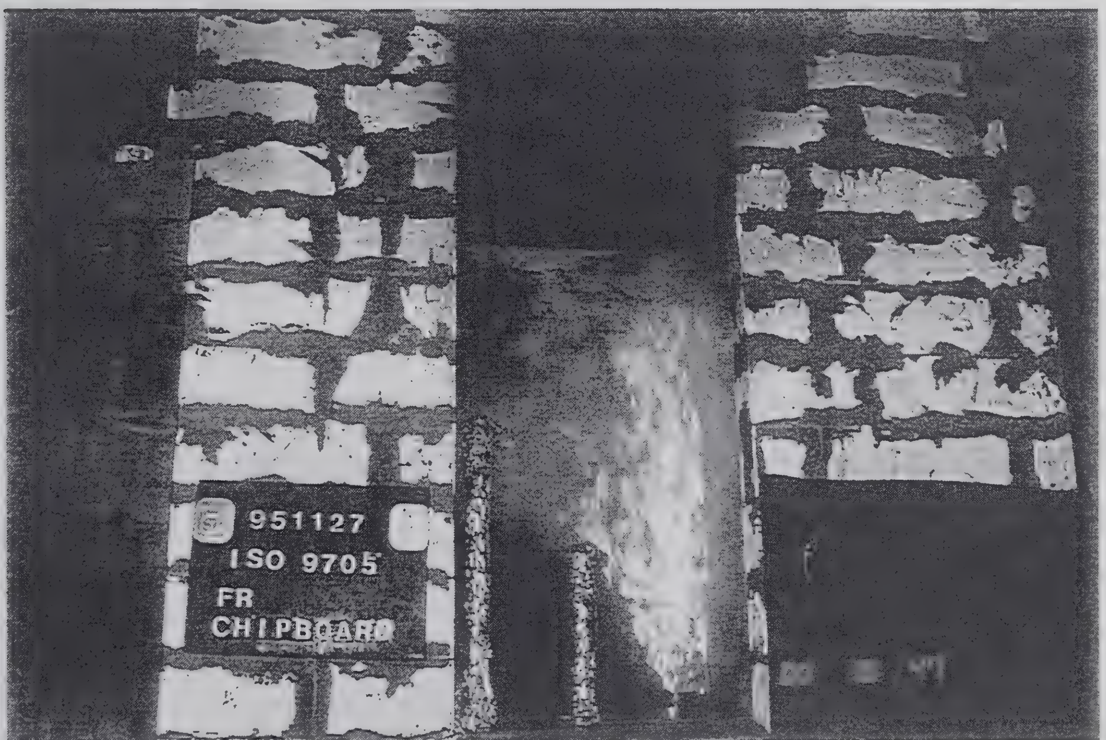


Photo no 6 Time 18:47 "FR chipboard"

HRR and SPR were still limited.

Test results, ISO 9705 (NT FIRE 025)

Product

3-layered FR polycarbonate panel

Mounting

The polycarbonate panels were screwed to a frame of light steel profiles which gave a spacing of 40 mm to the light weight concrete walls and ceiling.

Observations during test.

Time, [min:s]	Observations
0:00	Ignition of the burner, 100 kW.
0:15	The ceiling panel above the burner was deformed.
1:00	Melted material formed droplets.
3:00	The polycarbonate burned only in the vicinity of the burner flame, see photo no. 3.
3:40	SPR increased, the ceiling was no longer visible.
5:00	HRR and SPR decreased, the ceiling was again visible.
8:00	Some melted material burned on the floor close to the burner.
10:00	The burner output was increased to 300 kW. Melted material moved away from the burner flame, see photo no 4.
16:00	Flames were only seen in the burner corner and on the floor nearby the burner, see photo no. 5.
20:00	Gas shut off.
After test:	Some flaming was seen on the floor near the burner. All material in the ceiling was melted and had fallen down. Large portions of the walls were still intact, see photo no. 6.

Measured data

Thickness, mm	16
Area weight, kg/m^2	2.9

Conditioning

Temperature 20 ± 5 °C

Test results, graphs

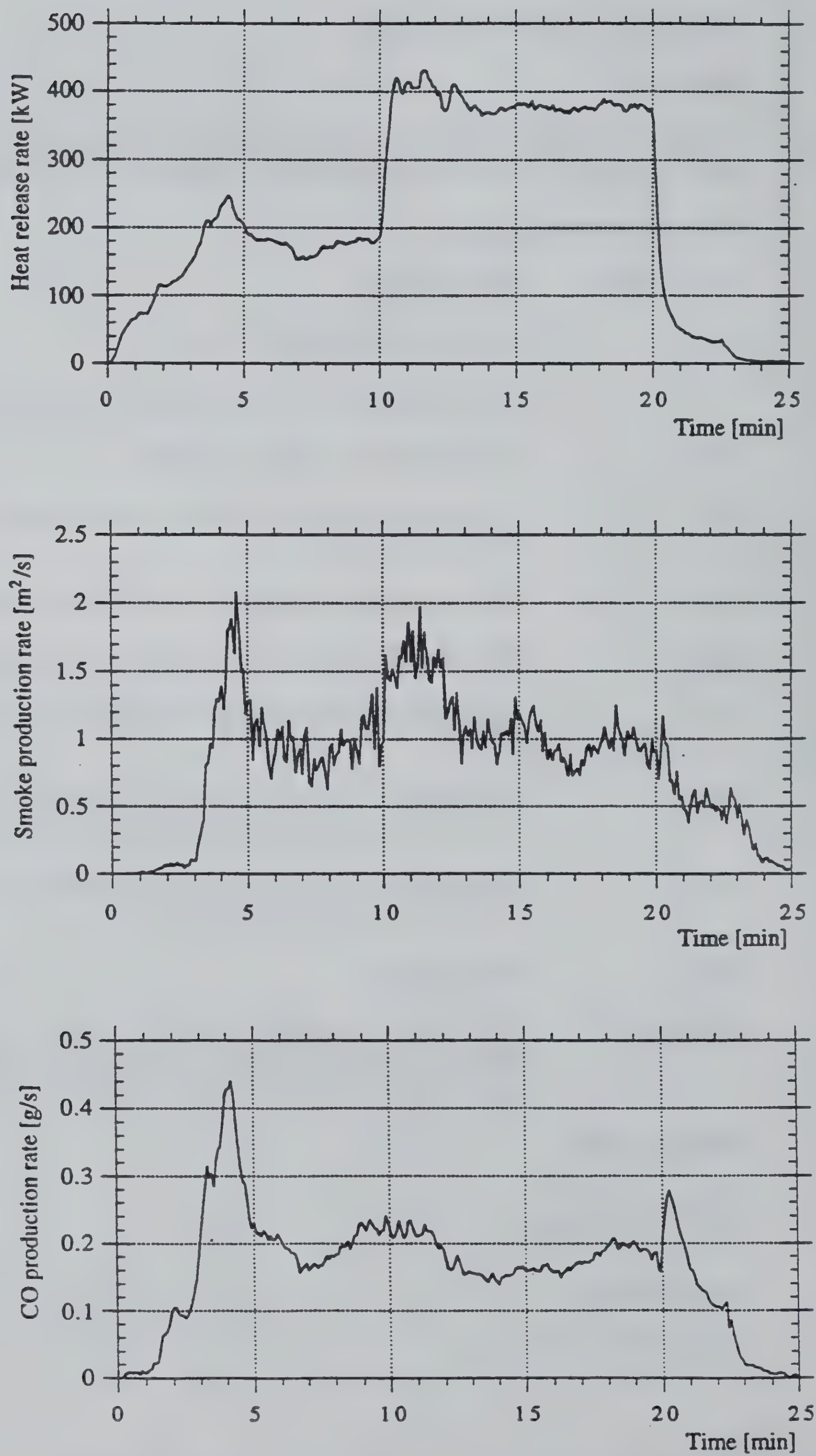


Figure 1 3-layered FR polycarbonate panel, heat release rate (including the HRR from the ignition source), smoke production rate and CO production rate

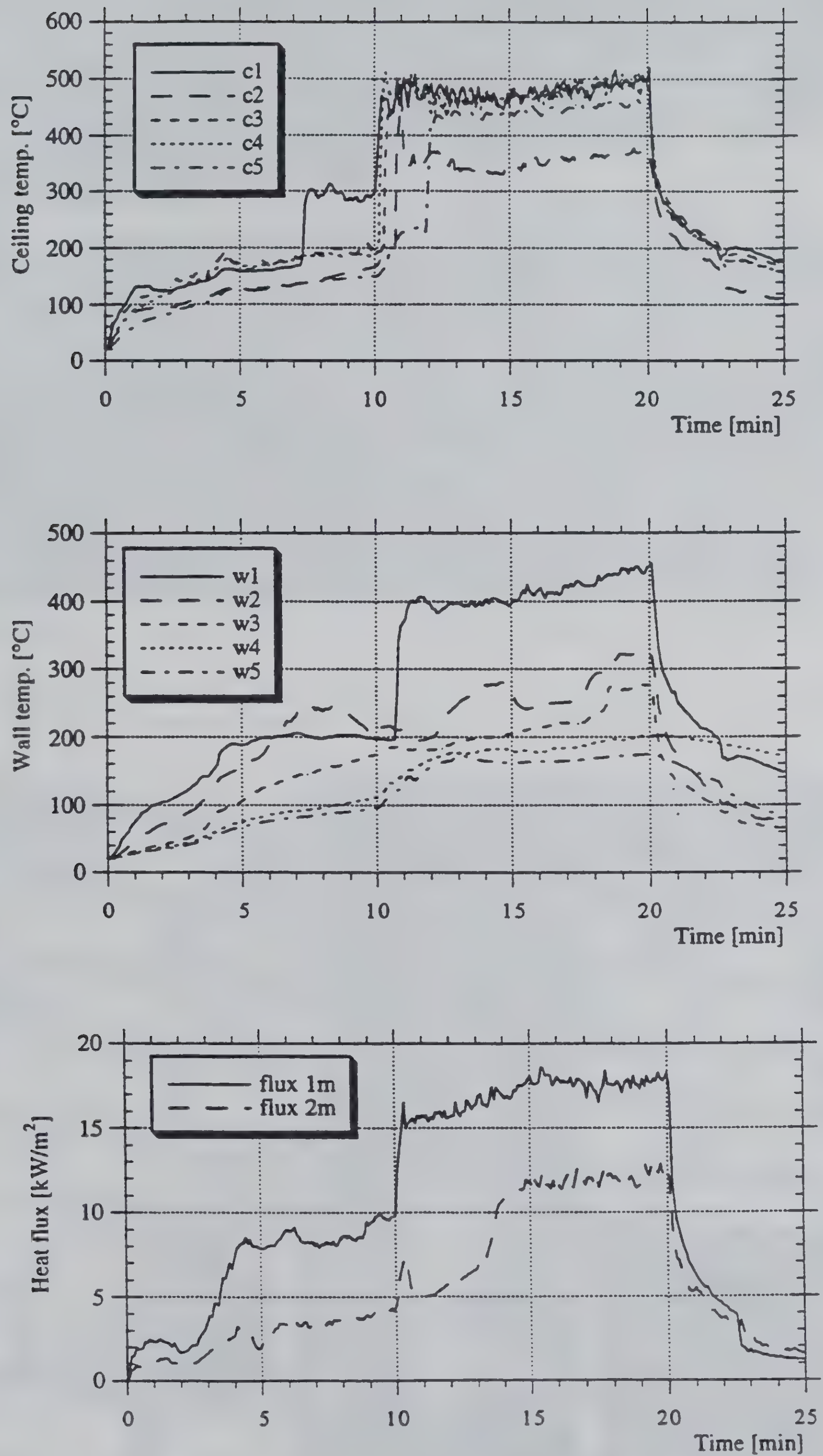


Figure 2 3-layered FR polycarbonate panel, ceiling temperatures, wall temperatures and heat flux, including the contribution from the ignition source.

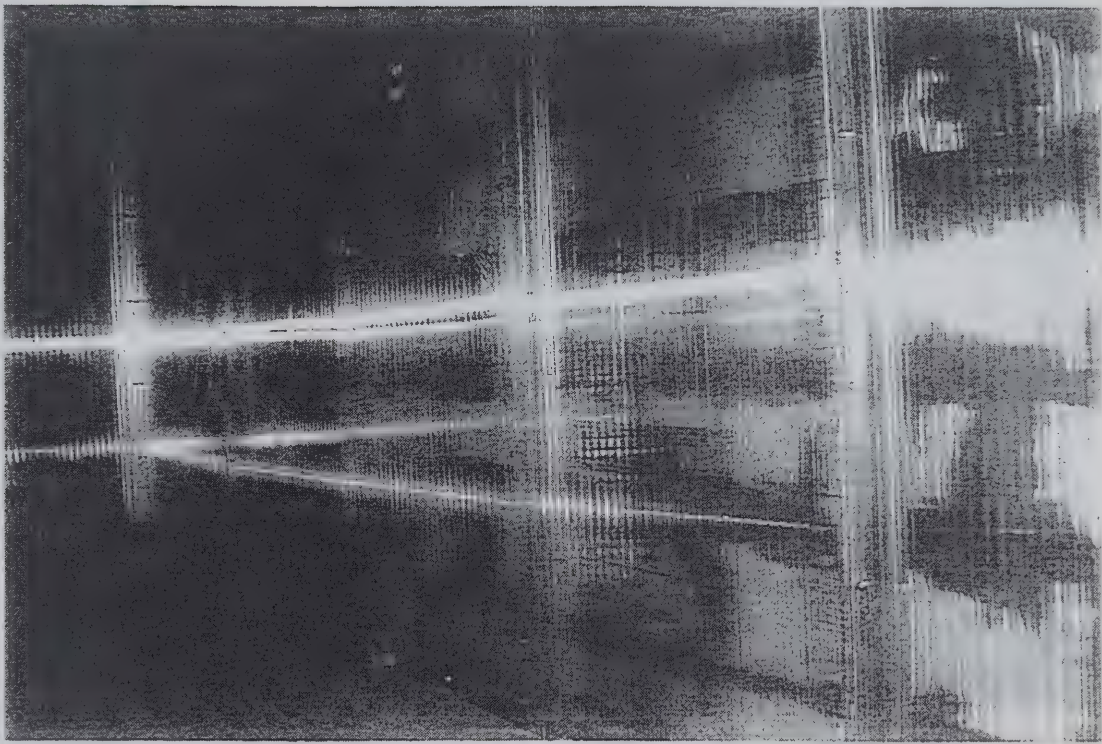


Photo no 1 Prior to test "3-layered FR polycarbonate panel"

The polycarbonate panels were screwed to a frame of light steel profiles which provided for a spacing of 40 mm to the light weight concrete walls and ceiling.

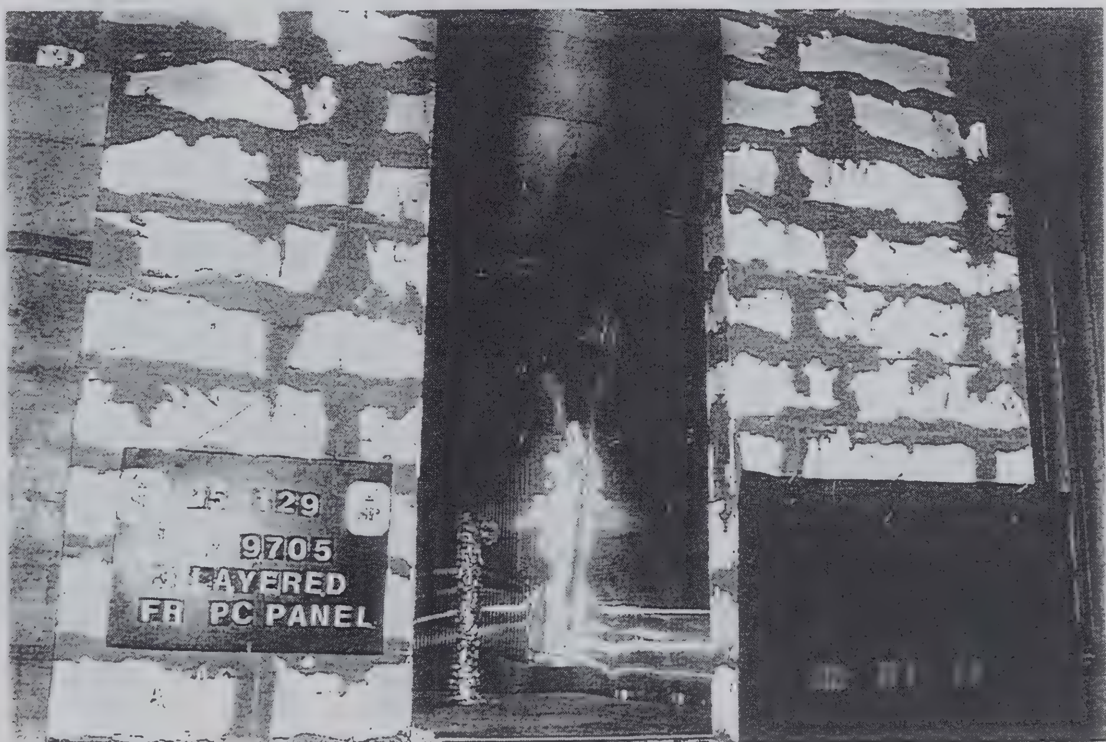


Photo no 2 Time 1:11 "3-layered FR polycarbonate panel"

Melted material formed droplets. Very limited HRR and SPR.

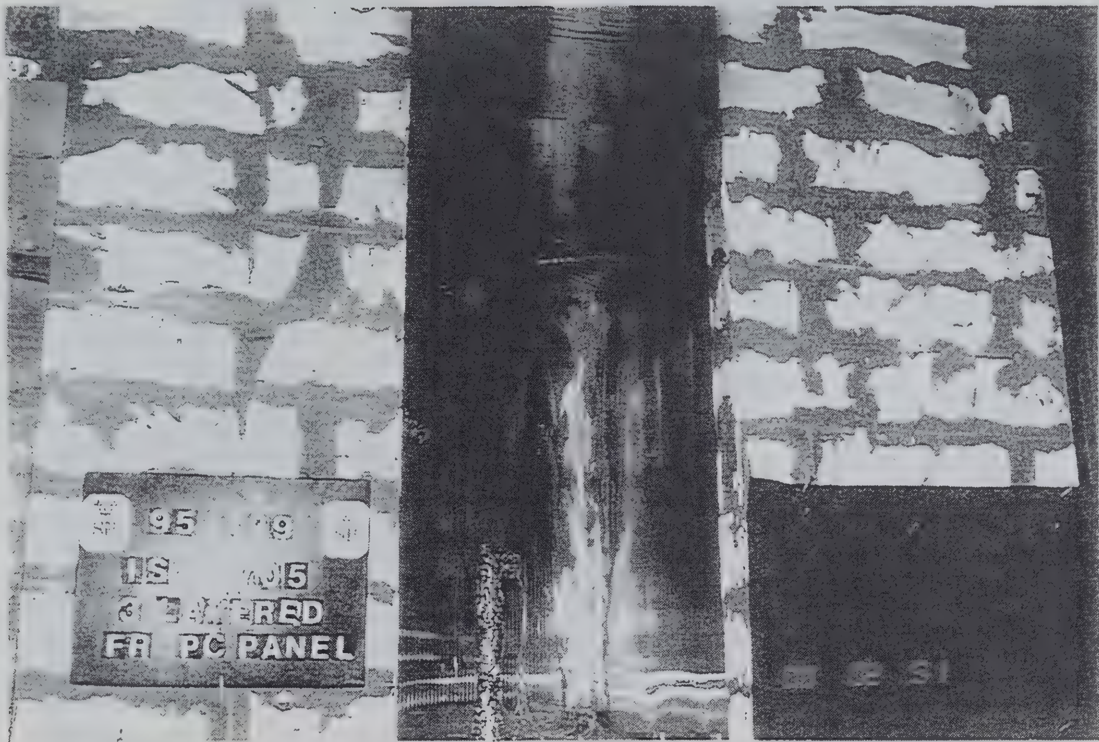


Photo no 3 Time 2:51 "3-layered FR polycarbonate panel"

The polycarbonate panels burnt only in the vicinity of the burner flame.

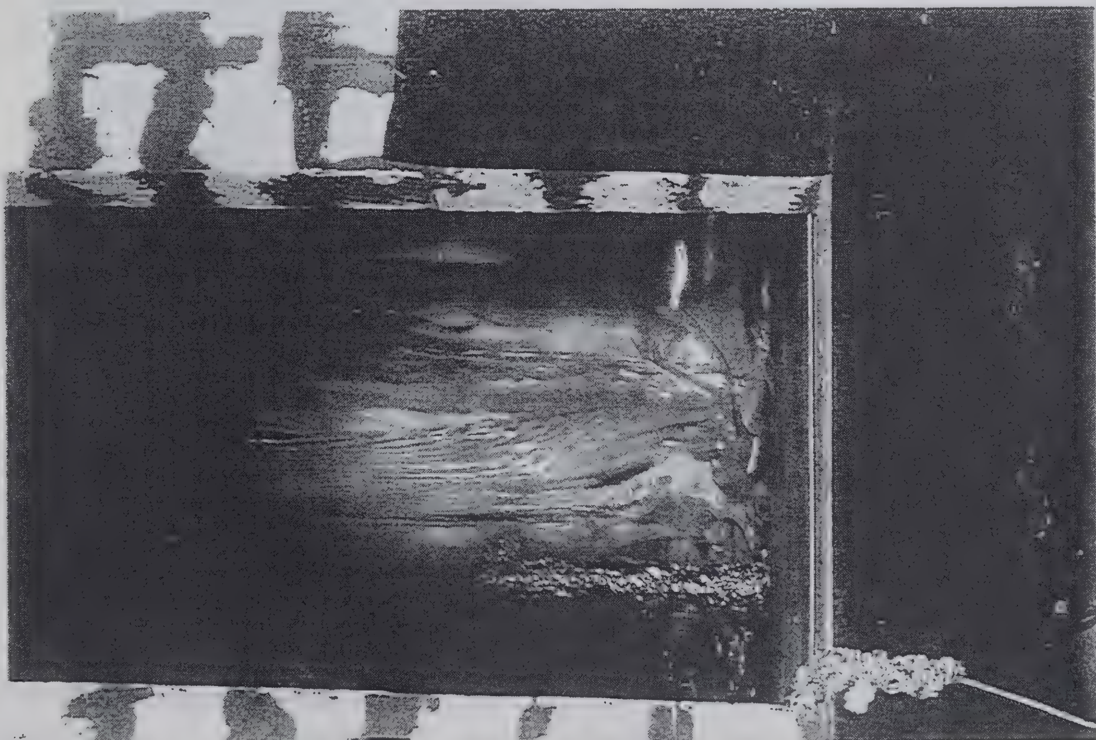


Photo no 4 Time 10:20 "3-layered FR polycarbonate panel"

The burner heat output had been increased to 300 kW. Melted material mowed away from the burner flame. HRR and SPR were still limited.

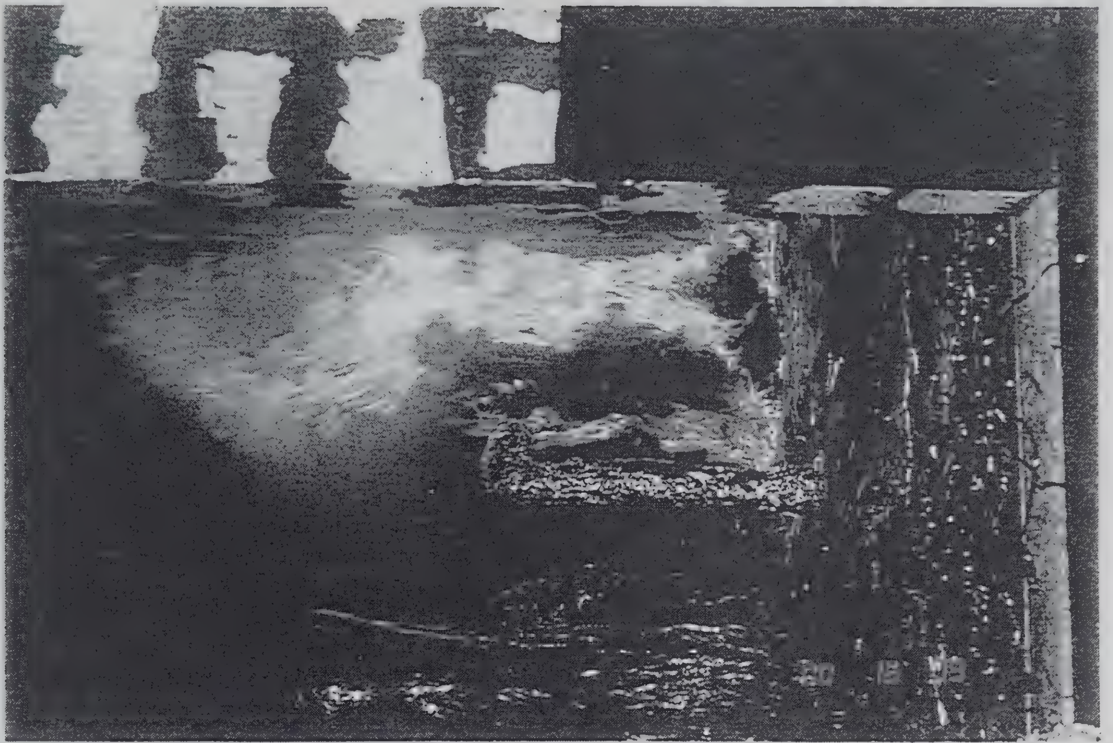


Photo no 5 Time 16:09 "3-layered FR polycarbonate panel"

Flames were only seen in the burner corner and on the floor near the burner.

Photo no 6 After test "3-layered FR polycarbonate panel"

All material in the ceiling had melted and fallen down. Large portions of the walls were still intact.

Test results, ISO 9705 (NT FIRE 025)

Product

FR expanded polystyrene board, 40 mm

Mounting

The polystyrene boards were glued to a non combustible board called "Promatek H", density 870 kg/m^3, with a water based contact adhesive called "Casco 3880". The non combustible boards were nailed to the light weight concrete walls and ceiling before the polystyrene boards were glued.

Observations during test.

Time, [min:s]	Observations
0:00	Ignition of the burner, 100 kW.
0:20	Burning droplets were formed.
0:40	Melted material run downwards the walls at the burner corner, see photo no. 2.
1:20	HRR and SPR increased rapidly. The ceiling was no longer visible. Melted material was dripping on the floor from the entire ceiling, see photo no. 3. Downward flame spread was seen.
1:25	A few flames were seen out the doorway.
2:30	The intensity of the fire was decreased. Only flaming in the burner corner was seen, see photo no. 4, and a few flames on the floor. The ceiling material was all melted.
10:00	The burner output was increased to 300 kW.
10:30	HRR and SPR increased.
11:00	Flaming was seen only in the burner corner, see photo no. 5.
11:50	A non-combustible backing board fell down from the ceiling. Some of the melted polystyrene on the floor was then screened from the heat radiation.
20:00	Gas shut off.
After test:	A few small flames were seen in the material after gas shut off. Most material was burned or melted. Some undamaged polystyrene slabs were still attached to the lower part of the walls.

Measured data

Thickness, mm	40
Density, kg/m^3	30

Conditioning

Temperature 20 ± 5 °C

Test results, graphs

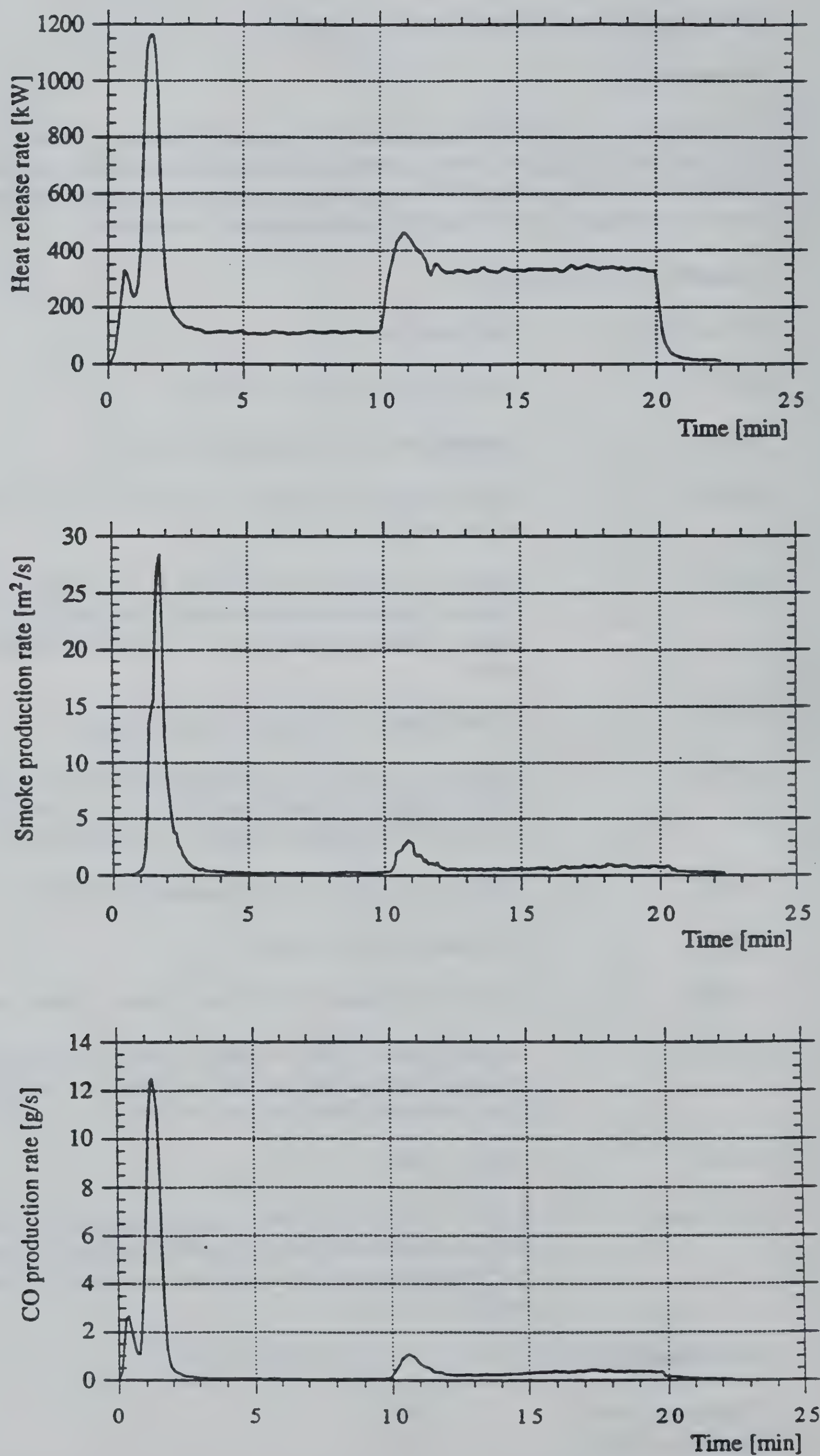


Figure 1 FR expanded polystyrene board (40 mm), heat release rate (including the HRR from the ignition source), smoke production rate and CO production rate

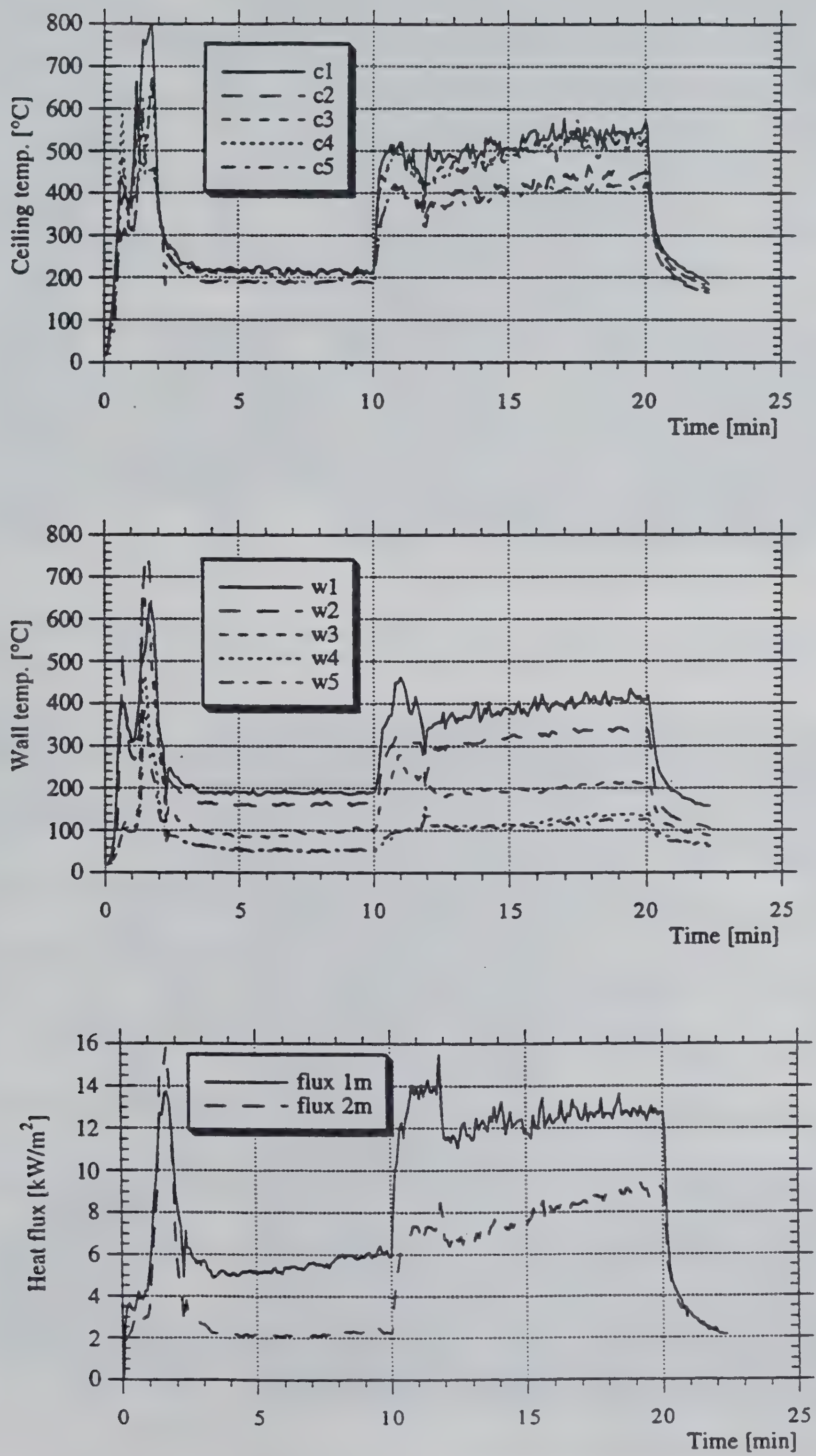


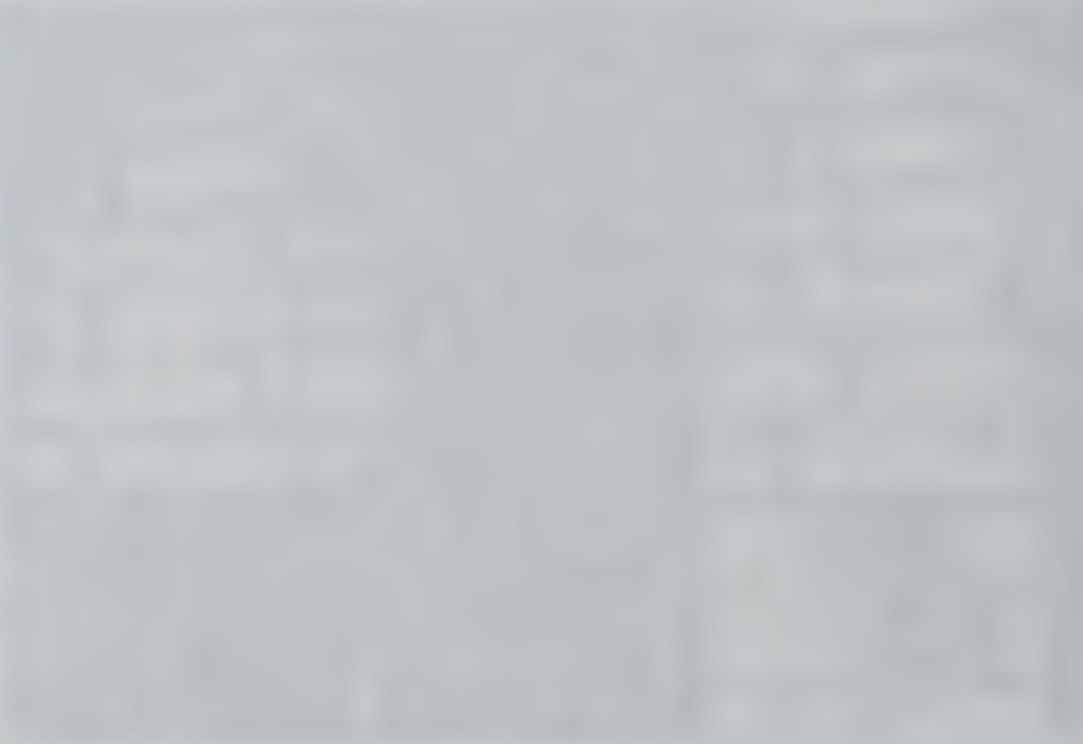
Figure 2 FR expanded polystyrene board (40 mm), ceiling temperatures, wall temperatures and heat flux, including the contribution from the ignition source.

Photo no 3 Time 1:22 "FR expanded polystyrene board, 40 mm"

HRR and SPR increased rapidly. The ceiling was no longer visible. Melted material was dripping to the floor from the entire ceiling. Downward flame spread was seen.

Photo no 4 Time 2:31 "FR expanded polystyrene board, 40 mm"

The intensity of the fire had decreased. Only flaming in the burner corner and a few flames on the floor was seen. The ceiling material was all melted.



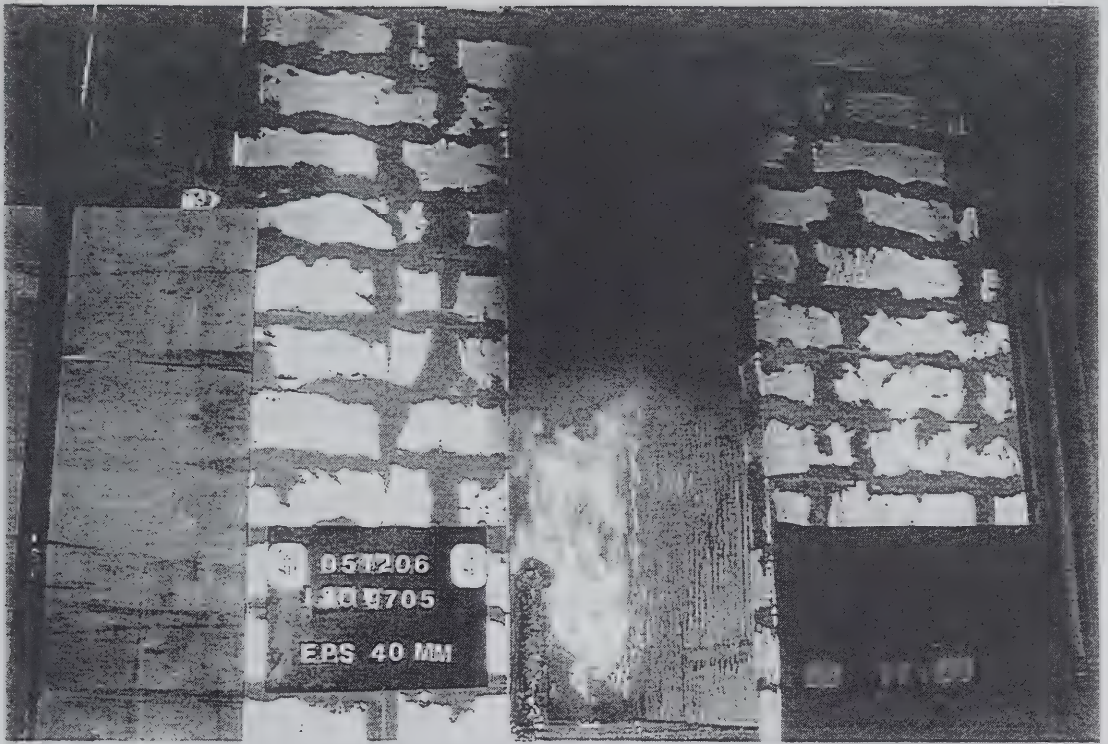


Photo no 5 Time 11:07 "FR expanded polystyrene board, 40 mm"

The burner heat output had been increased. Flaming was seen in the burner corner only.

Photo no 6 After test "FR expanded polystyrene board, 40 mm"

Most material had burnt or melted. Some undamaged polystyrene slabs were still attached to the lower part of the walls..

Test results, ISO 9705 (NT FIRE 025)

Product

FR expanded polystyrene board, 80 mm

Mounting

The polystyrene boards were glued to a non combustible board called "Promatek H", density 870 kg/m^3, with a water based contact adhesive called "Casco 3880". The non combustible boards were nailed to the light weight concrete walls and ceiling before the polystyrene boards were glued.

Observations during test.

Time, [min:s]	Observations
0:00	Ignition of the burner, 100 kW.
0:15	The material in the ceiling above the burner started to melt, see photo no. 2.
0:30	Melted material run downwards the walls at the burner corner, see photo no. 3.
1:25	HRR and SPR increased rapidly. The ceiling was no longer visible, see photo no. 4.
1:45	Melted material was dripping to the floor from the entire ceiling. Downward flame spread was seen. A few flames were seen out the doorway, see photo no. 5.
2:15	The intensity of the fire decreased.
2:45	Only flaming in the burner corner was seen, see photo no. 6.
3:00	All ceiling and approximately 50 % of the walls were consumed or melted.
7:00	A small pool fire was seen on the floor nearby the burner corner.
10:00	The burner output was increased to 300 kW.
10:20	Some increase of HRR and SPR was seen due to burning melted material near the burner, see photo no. 7.
13:00	HRR and SPR started to increase rapidly, see photo no. 8.
13:21	Flames out the doorway. Downward flame spread was seen on the walls, see photo no. 9.
13:29	Gas shut off, extinguishment.
After test:	Most material had burned or melted, see photo no. 10.

Measured data

Thickness, mm	80
Density, kg/m^3	17

Conditioning

Temperature 20 ± 5 °C

Test results, graphs

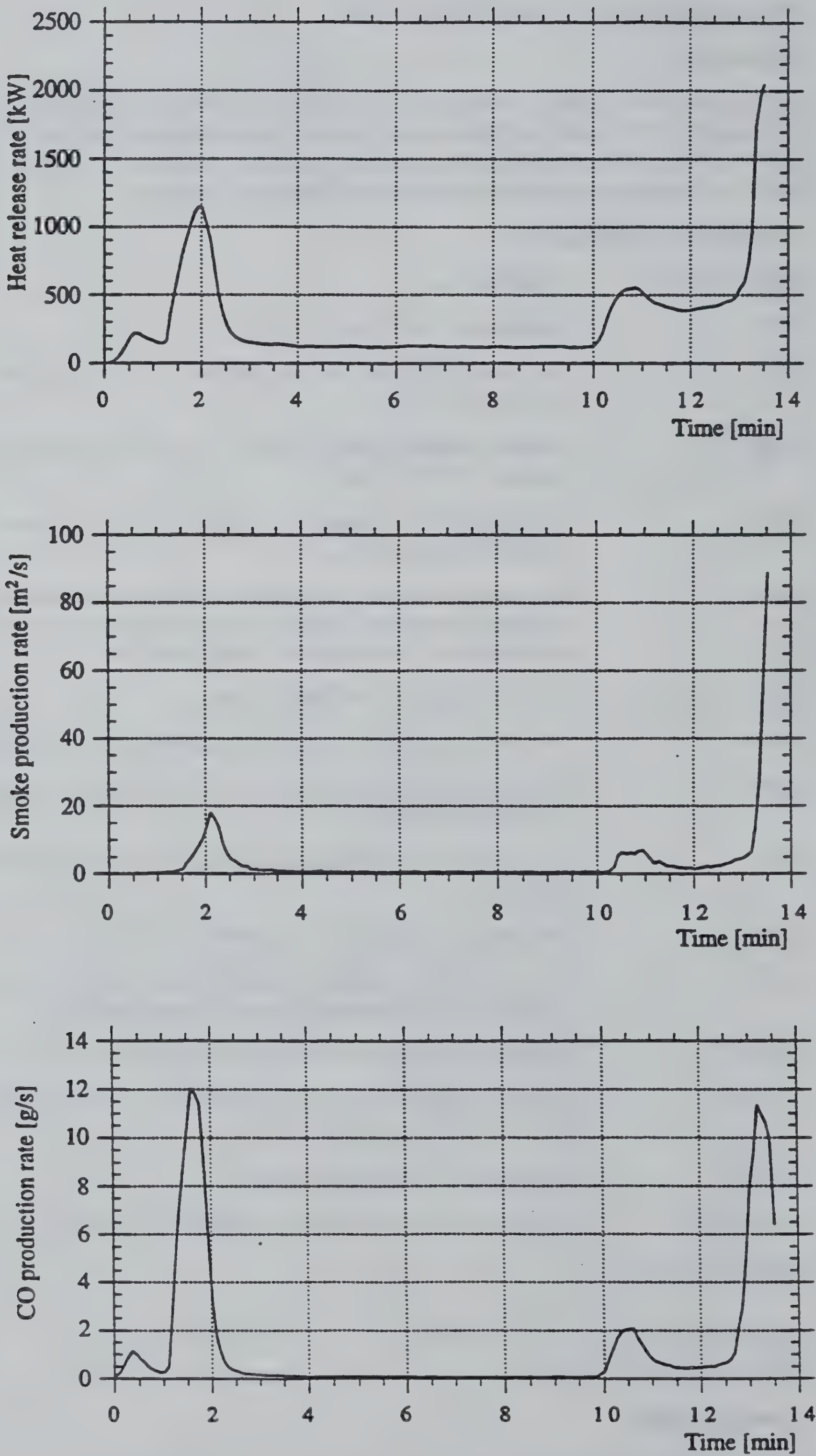


Figure 1 FR expanded polystyrene board (80mm), heat release rate (including the HRR from the ignition source), smoke production rate and CO production rate

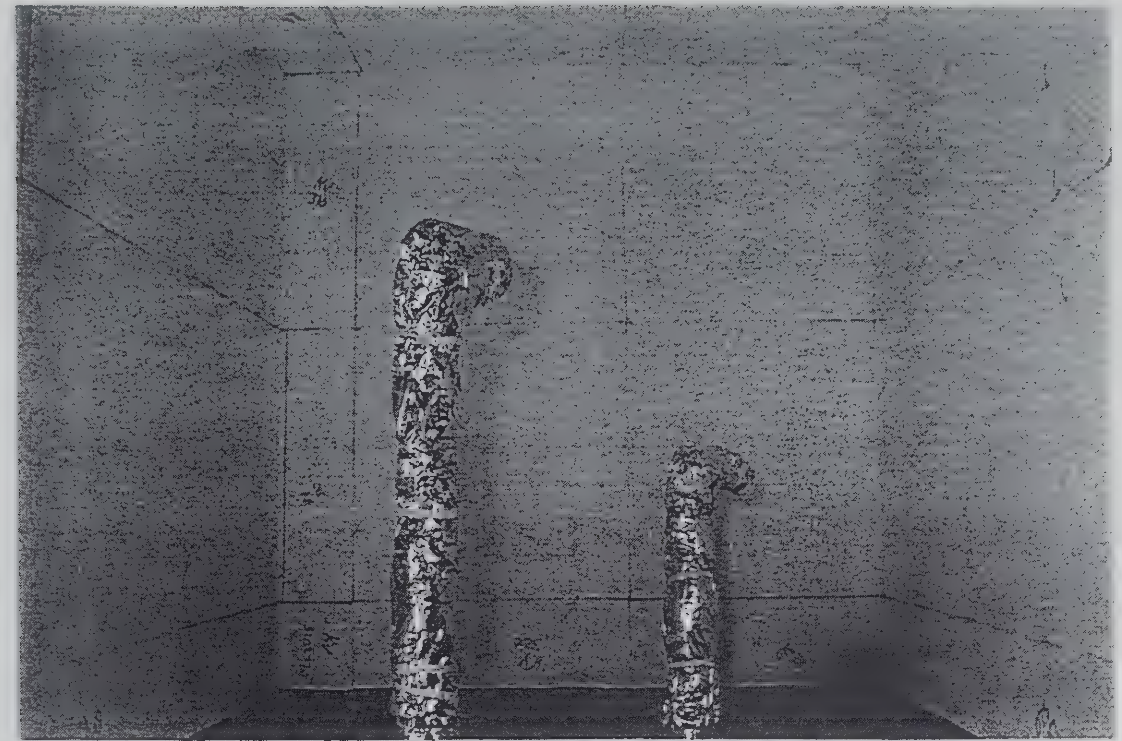


Photo no 1 Prior to test "FR expanded polystyrene board, 80 mm"

The polystyrene boards were glued to a non combustible board. The non combustible boards were nailed to the light weight concrete walls and ceiling.

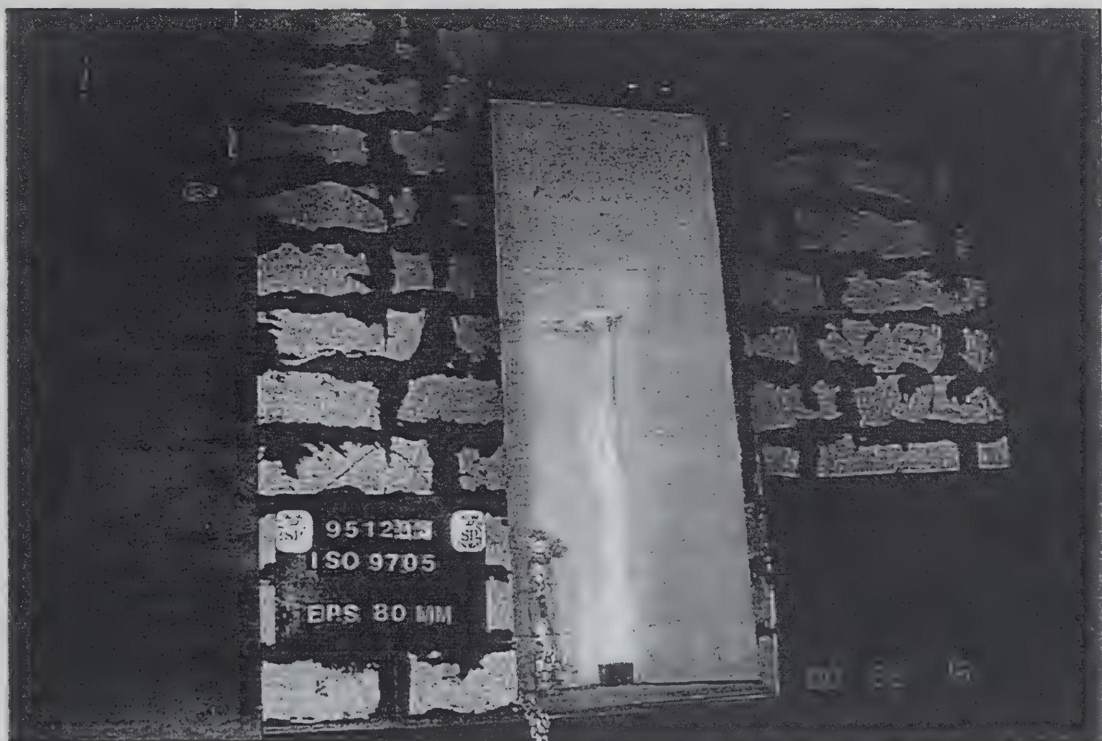
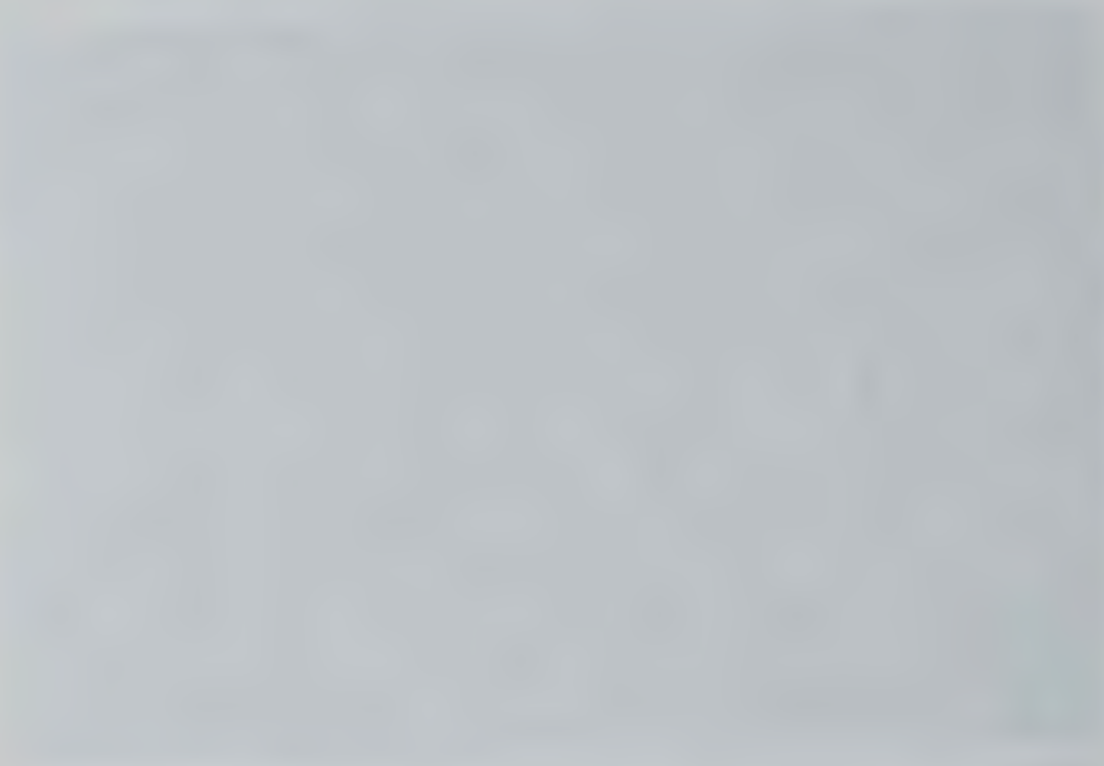


Photo no 2 Time 0:16 "FR expanded polystyrene board, 80 mm"

The material in the ceiling above the burner started to melt.



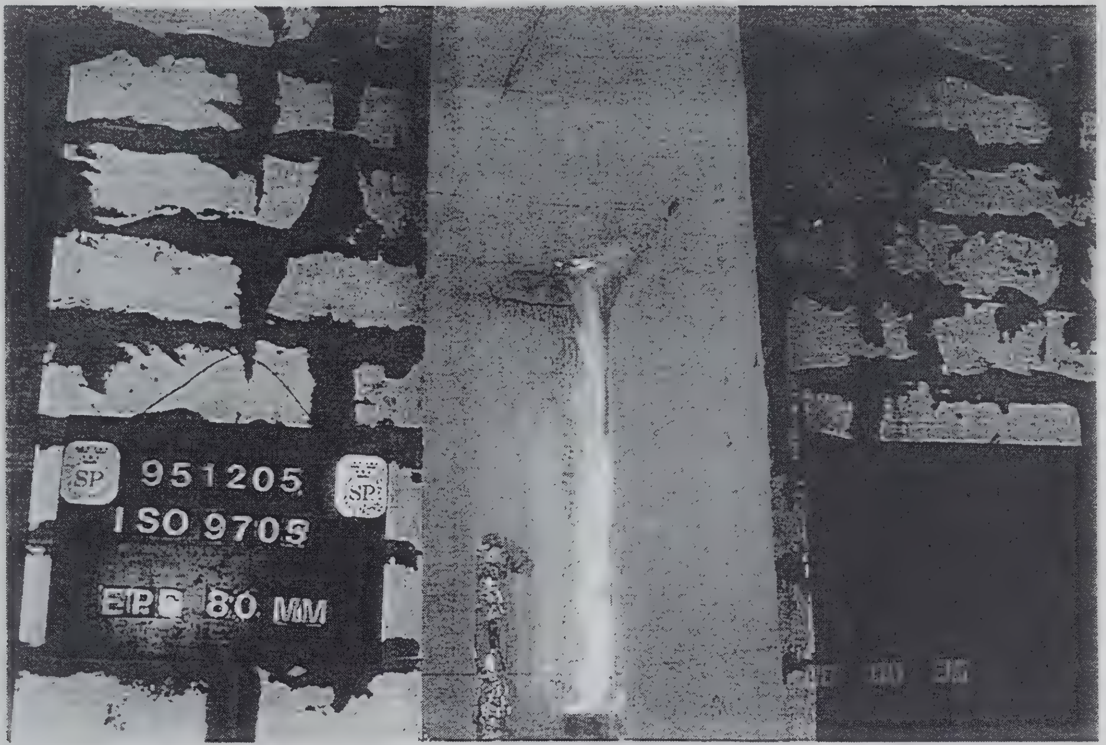


Photo no 3 Time 0:36 "FR expanded polystyrene board, 80 mm"

Melted material run downwards the walls at the burner corner.

Photo no 4 Time 1:26 "FR expanded polystyrene board, 80 mm"

HRR and SPR increased rapidly. The ceiling was no longer visible.

Photo no 5 Time 1:51 "FR expanded polystyrene board, 80 mm"

Melted material was dripping to the floor from the entire ceiling. Downward flame spread was seen. A few flames were seen out the doorway.

Photo no 6 Time 2:46 "FR expanded polystyrene board, 80 mm"

Only flaming in the burner corner was seen.

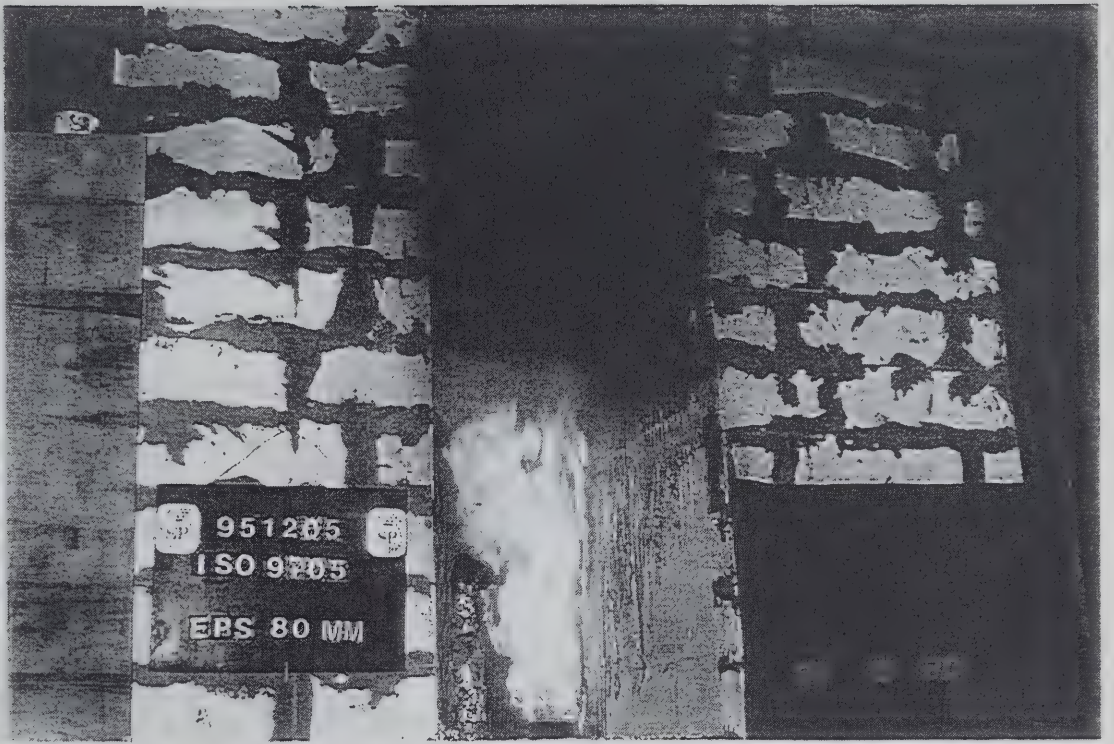


Photo no 7 Time 10:20 "FR expanded polystyrene board, 80 mm"

The burner heat output had been increased to 300 kW. Some increase of HRR and SPR was seen due to melted material near the burner that ignited

Photo no 8 Time 13:11 "FR expanded polystyrene board, 80 mm"

HRR and SPR started to increase rapidly.

Photo no 9 Time 13:23 "FR expanded polystyrene board, 80 mm"

Flash over was reached. High HRR and SPR, flames out the doorway. Downward flame spread was seen on the walls

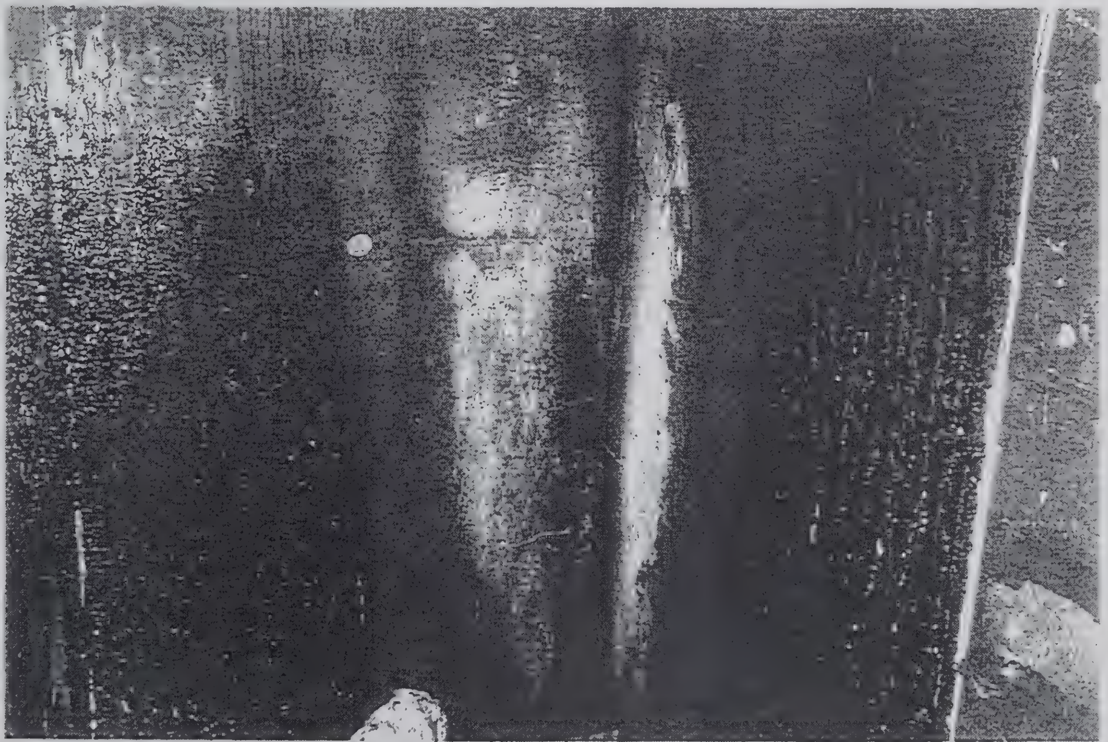


Photo no 10 After test "FR expanded polystyrene board, 80 mm"

Most material had burnt or melted.

Test results, ISO 9705 (NT FIRE 025)

Product

Plywood

Mounting

The plywood was nailed to the lightweight concrete walls and ceiling.

Observations during test.

Time, [min:s]	Observations
0:00	Ignition of the burner, 100 kW.
0:45	The material in the burner corner and in the ceiling above the burner was ignited, see photo no. 2.
1:30	More than 50 % of the ceiling was ignited and flame spread was starting downward the walls, see photo no. 3.
2:14	Flames were seen out the doorway. SPR increased. Flame spread was seen approximately 1 m down the walls, see photo no. 4.
2:58	The ceiling and most parts of the walls were engulfed in flames. HRR peaked at approximately 2 MW.
3:00	Gas shut off.
3:05	Extinguishment.
After test:	Most parts of the walls and ceiling were charred.

Measured data

Thickness, mm	14
Density, kg/m^3	440
Moisture content, %	11.3

Conditioning

Temperature 20 ± 5 °C

Test results, graphs

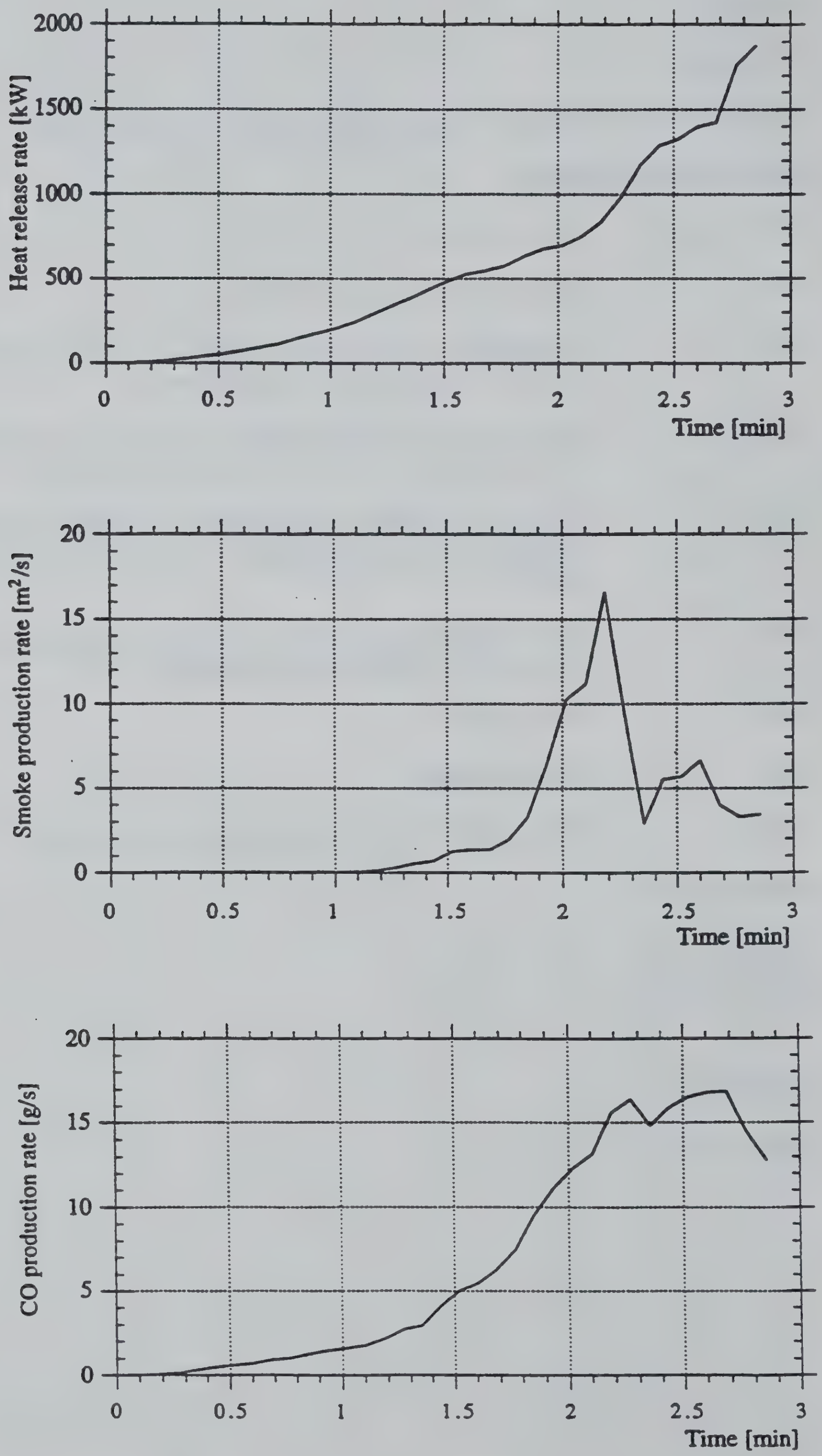


Figure 1 Plywood, heat release rate (including the HRR from the ignition source), smoke production rate and carbon monoxide production rate

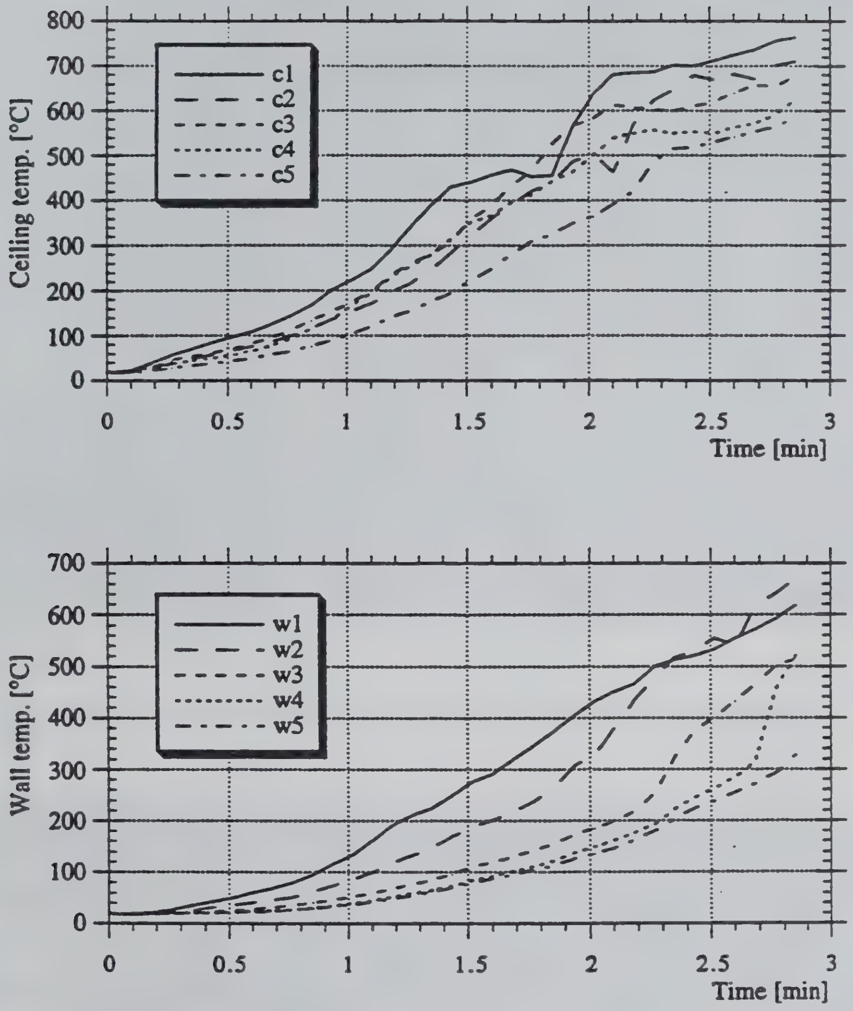


Figure 2 Plywood, ceiling temperatures, wall temperatures and heat flux, including the contribution from the ignition source.

Photo no 1 Prior to test "Plywood"

The plywood was nailed to the light weight concrete walls and ceiling.

Photo no 2 Time 0:46 "Plywood"

The material in the burner corner and in the ceiling above the burner had ignited

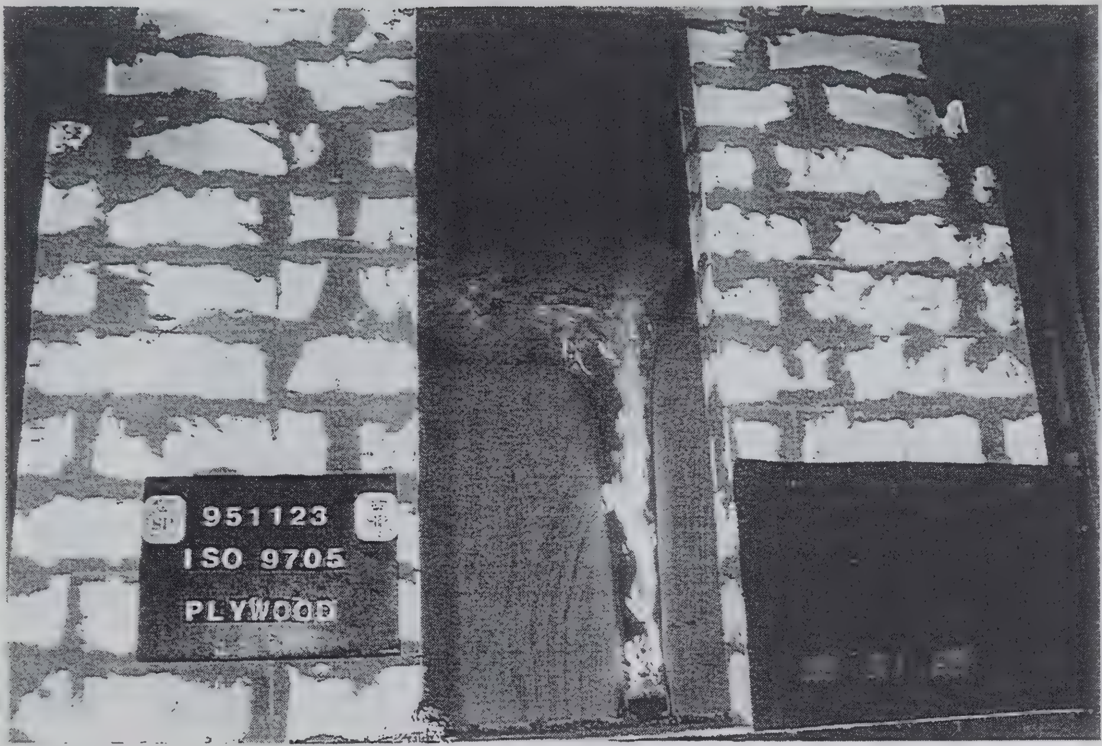


Photo no 3 Time 1:28 "Plywood"

More than 50 % of the ceiling had ignited and flame spread was starting downward the walls.

Photo no 4 Time 2:14 "Plywood"

Flames were seen out the doorway. SPR increased. Flame spread was seen approximately 1 m down the walls.

Photo no 5 Time 2:58 "Plywood"

Flash over was reached. The ceiling and most parts of the walls were engulfed in flames. HRR peaked at approximately 2 MW.

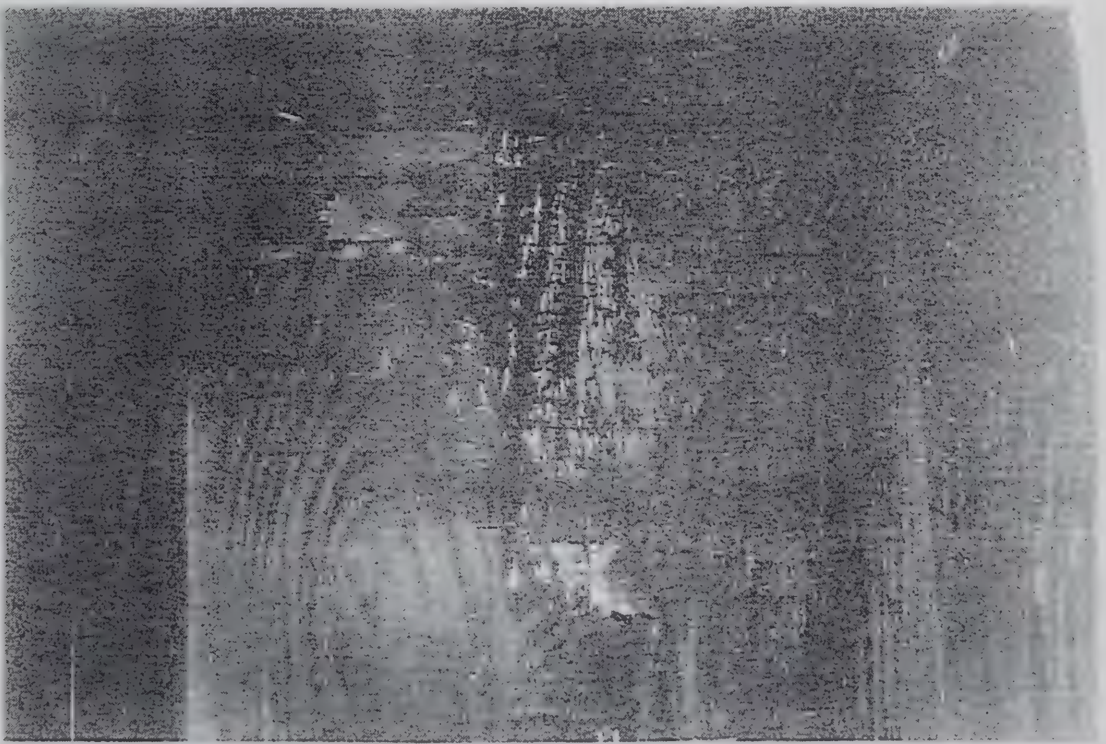


Photo no 6 After test "Plywood"

Most parts of the walls and ceiling were charred.

Test results, ISO 9705 (NT FIRE 025)

Product

FR Plywood

Mounting

The FR plywood was nailed to the lightweight concrete walls and ceiling.

Observations during test.

Time, [min:s]	Observations
0:00	Ignition of the burner, 100 kW.
0-10:00	Only limited burning in the burner corner was seen. Low SPR.
10:00	The burner output was increased to 300 kW.
10:10	Flame spread in the ceiling was seen. SPR increased, see photo no. 3.
10:35	Flames out the doorway.
10:45	Downward flame spread was seen on the walls. SPR decreased, see photo no. 4.
11:10	Gas shut off.
11:16	HRR decreased, see photo no. 5.
11:53	The material started to self extinguish, see photo no. 6.
After test:	Most parts of the walls and ceiling were charred.

Measured data

Thickness, mm	15
Density, kg/m^3	460
Moisture content, %	9.8

Conditioning

Temperature 20 ± 5 °C

Test results, graphs

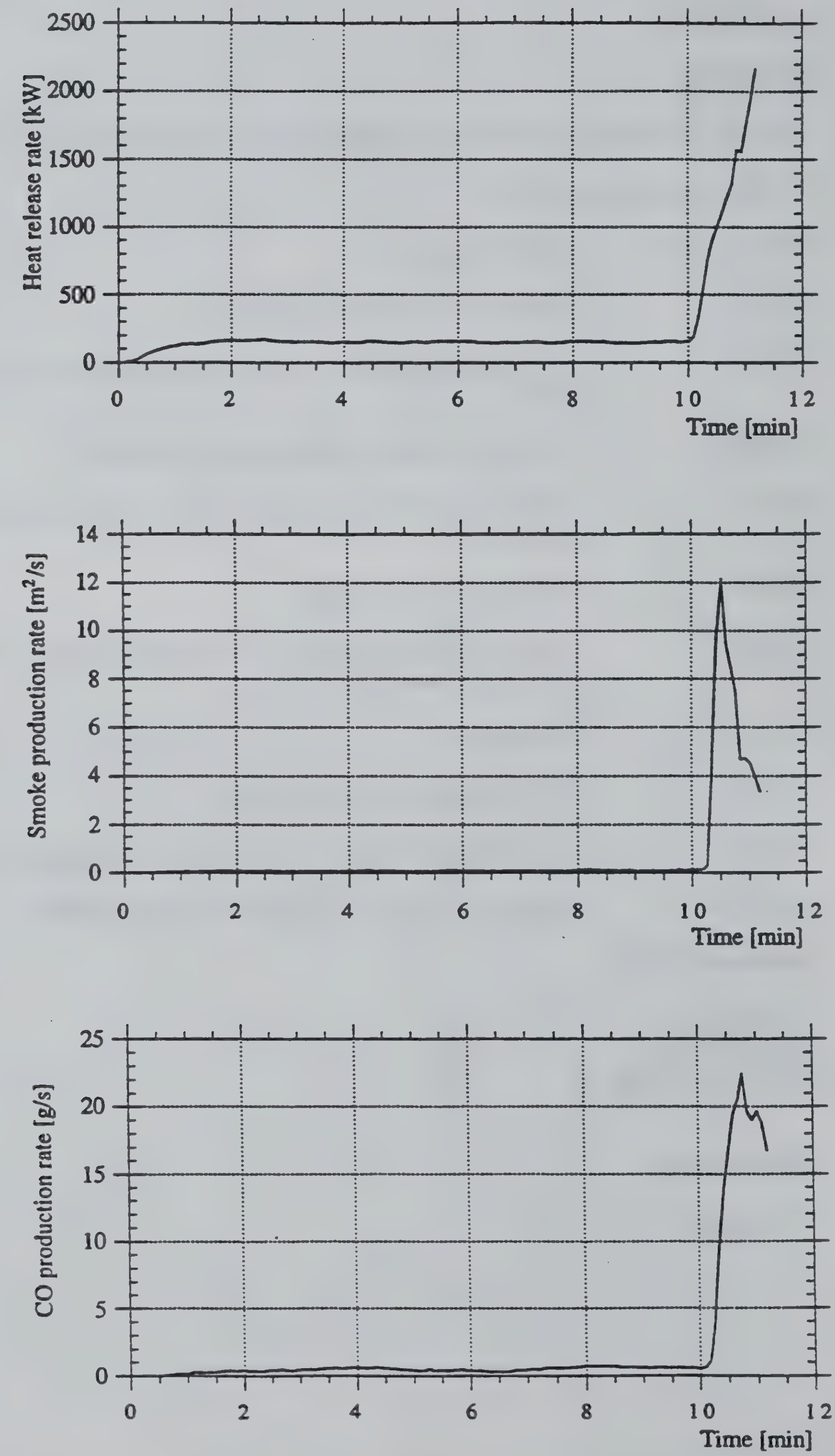


Figure 1 FR plywood, heat release rate (including the HRR from the ignition source), smoke production rate and carbon monoxide production rate

Photo no 1 Prior to test "FR Plywood"

The FR plywood was nailed to the light weight concrete walls and ceiling.

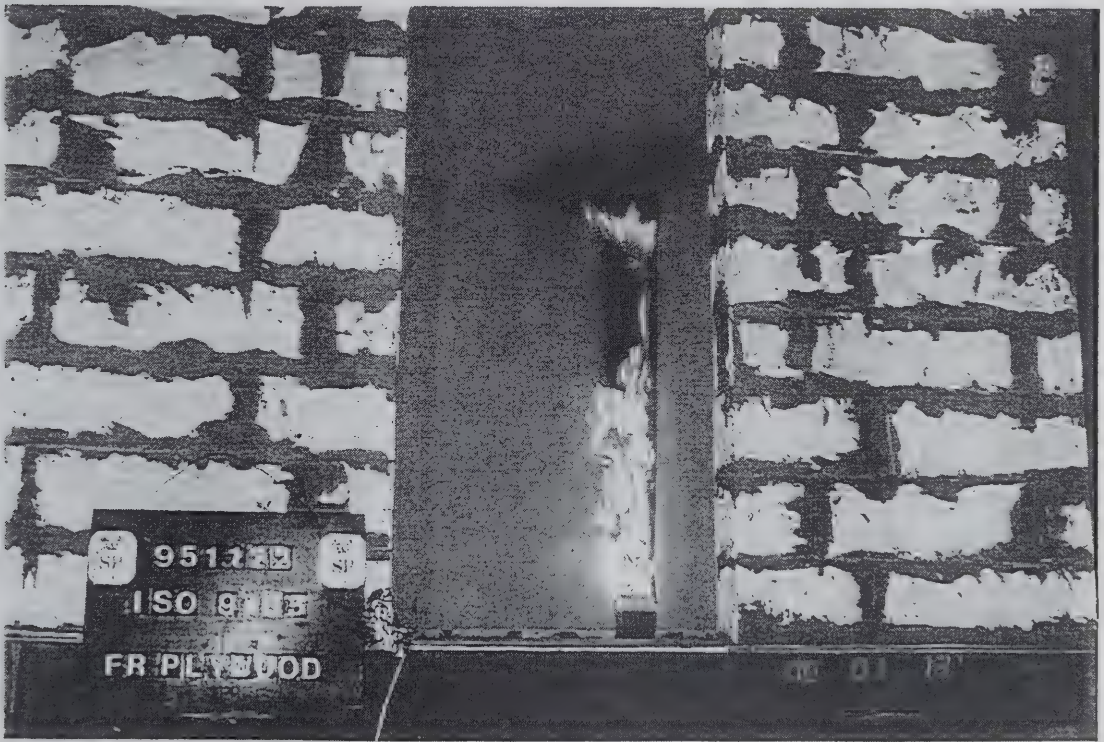


Photo no 2 Time 1:13 "FR Plywood"

Limited burning in the vicinity of the burner flame.

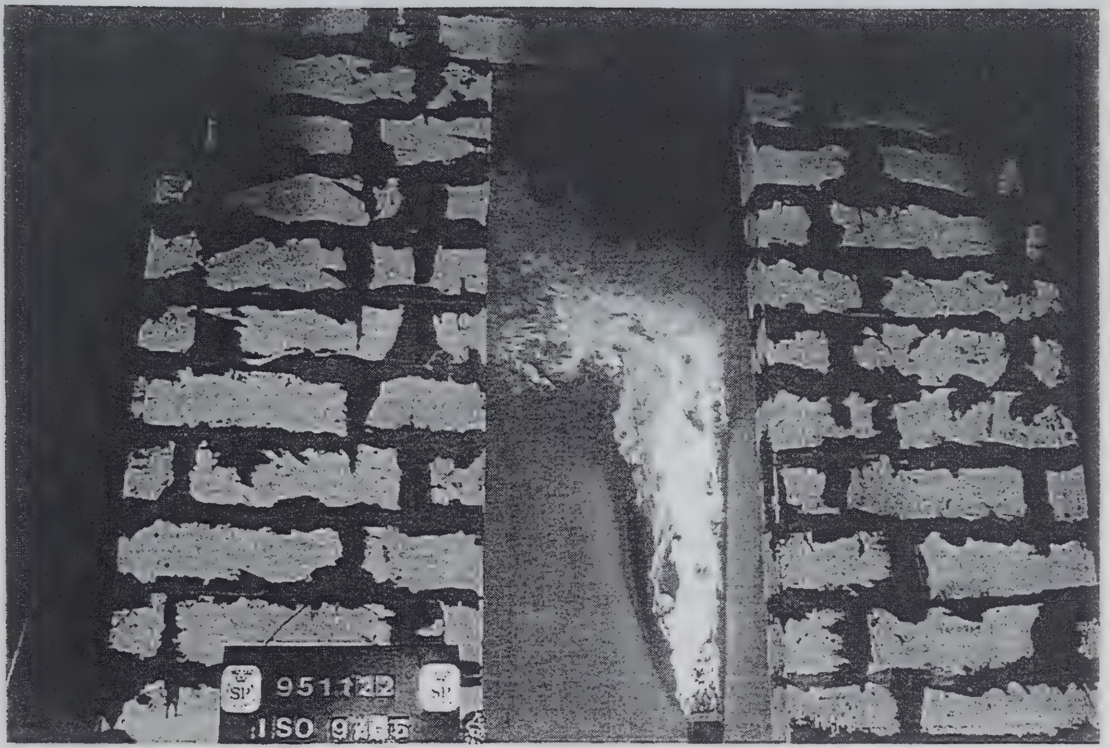


Photo no 3 Time 10:12 "FR Plywood"

The burner heat output had been increased to 300 kW. Flame spread in the ceiling was seen. SPR increased.

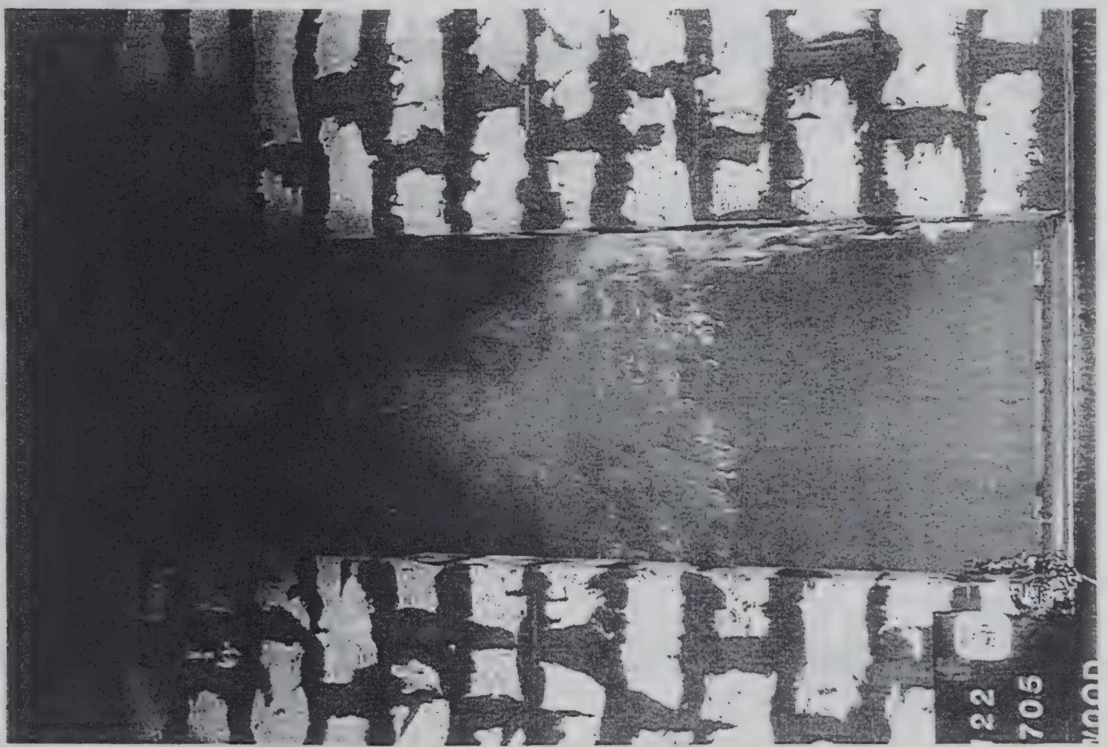


Photo no 4 Time 10:45 "FR Plywood"

Flash over was reached. Downward flame spread was seen on the walls. SPR decreased.

Photo no 5 Time 11:16 "FR Plywood"

The gas burner had been shut off due to flash over. HRR decreased.

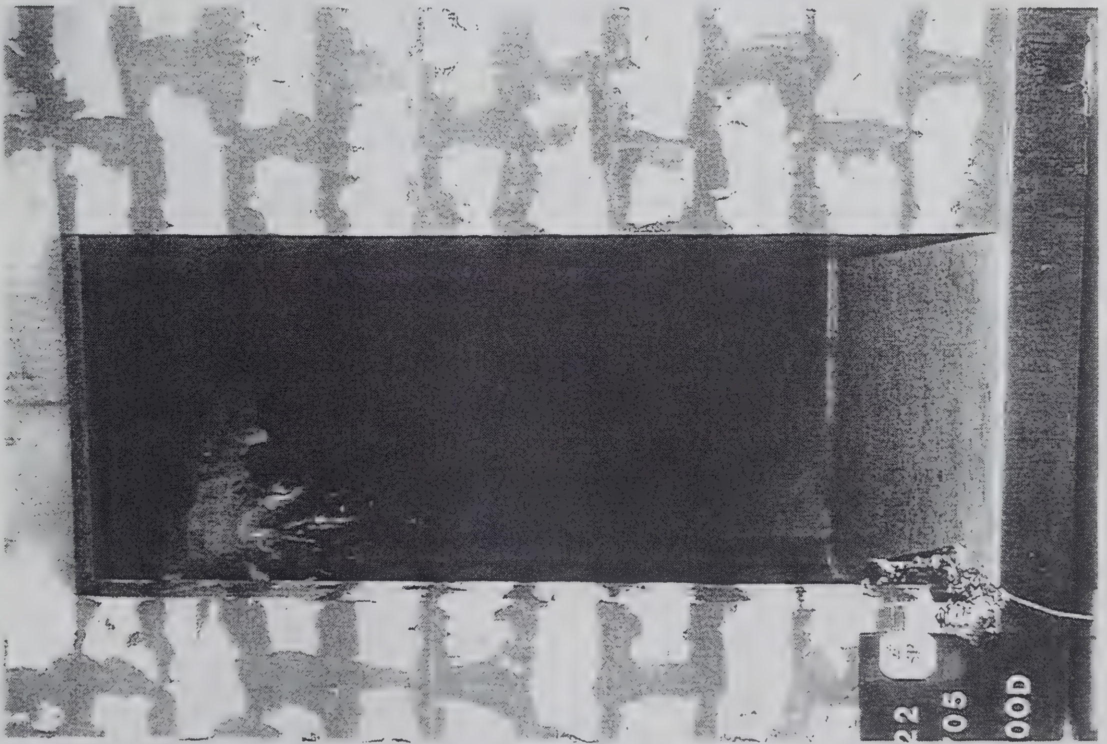


Photo no 6 Time 11:53 "FR Plywood"

The material self-extinguished.

Appendix D – Quintiere's Fire Growth Model

- D.1 Quintiere, J. G., "A Simulation Model for Fire Growth on Materials Subject to a Room/Corner Test", *Fire Safety Journal*, Volume 18, 1992.
- D.2 Fire Growth Model Source Code

D.1 — Quintiere J G., "A Simulation Model for Fire Growth on Materials Subject to a Room/Corner Test", Fire Safety Journal, *Volume 18, 1992.*

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A Simulation Model for Fire Growth on Materials Subject to a Room-Corner Test

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ABSTRACT

A mathematical model has been developed to simulate fire growth on wall and ceiling materials when subject to a room-corner fire test exposure. The model predicts the area of burning, the upper layer gas temperature, and the rate of energy release as a function of time. Material fire property data are developed from apparatuses described in ASTM E 1321 and E 1354. The results compare favorably to experimental data generated in Sweden for 13 materials tested. Furthermore, the model shows the sensitivity to 'flashover' for thin materials relative to small variations in their property data.

NOTATION

A	area
b	parameter defined in eqn (14)
c	specific heat
d	depth of room
D	side of square burner
g	acceleration due to gravity
h	convective heat transfer coefficient
H	height of room, vent
k	thermal conductivity
k_f	empirical constant, eqn (7)
L	effective heat of gasification
n	empirical power, eqn (7)

Fire Safety Journal 0379-7112/93/$06·00

q	heat
Q	energy release
t	time
T	temperature
w	width of room
x	lateral position
y	upward position
z	downward position
ρ	density
τ	dummy variable for time, eqn (1)
ΔH	heat of combustion

Subscripts

b	burn-out
f	flame
ig	ignitor, ignition
min	minimum
p	pyrolysis
s	surface
s, o	surface responding to ignitor flame heat flux
o	initial
∞	ambient

Superscripts

$(\dot{\ })$	per unit time
$(\ )'$	per unit width
$(\ )''$	per unit area

INTRODUCTION

For many years the regulation of interior finish materials applied to the walls, floor and ceiling of a building has been determined by a flammability test. The criterion for acceptance is usually based on a rating scale for the flammability test. This gives a relative level of performance for the material's potential for fire growth. Other fire safety elements such as smoke obscuration and toxicity are treated in a similar fashion. The limitations of a relative ranking scale based on a single test is that it is not necessarily applicable to the material's fire growth potential in its actual application.

Lack of confidence in the test ranking approach led to the development of a standard room test to investigate the material's fire growth potential.[1] Although the room test is conducted at a more realistic

scale, it still only offers one result, e.g. the time to achieve a specific energy release or flashover. The effect of the ignition source and room geometry are not known without conducting a series of expensive tests.

Consequently, an alternative to conducting full-scale tests has the hope of using material fire property data to predict such results for a wide range of conditions. The first attempt for making predictions of room fire growth over interior finish materials was done by Smith.[2] He employed material energy release rate data from a dynamic calorimetry apparatus.[3] More recently Karlsson and Magnusson[4] developed a model for room fire growth on wall and ceiling materials which incorporated data from two new fire property test methods.[5,6] Both of these models used empirical methods for computing flame spread. As an attempt to improve this modeling approach, Cleary and Quintiere[7] presented a simple, but complete accounting for all modes of flame spread which govern growth on a wall and a ceiling. Although successful agreement was found with data, their model lacked a direct accounting of room thermal feedback, and selected energy release rate data from the Cone Calorimeter at an arbitrary irradiance level. The simulation model described in this paper attempts to eliminate these two limitations. However, as will be seen, the new model requires the specification of the ignition source and spreading flame heat flux which will still introduce some uncertainty. Although Smith[2] computed the flame heat flux in his model, this author does not believe that accurate results are possible by purely theoretical means. Instead, heat flux correlations developed from controlled experiments will be more reliable.

The validity of any model must be judged on the soundness of its components, its completeness, and its ability to predict experimental results. Two of the models described above[4,7] have been evaluated against an extensively instrumented series of room-corner fire experiments for 13 materials.[8] A complete set of fire property data was also available for the 13 materials.[7,9] Both of the models,[4,7] as well as empirical models by Wickström and Göransson[10] and Östman and Nussbaum,[11] have all given good predictive results for the time to flashover in these experiments. All of these models have used the rate of energy release per unit area ($\dot{Q}''$) as a significant input parameter. The issues that remain are (1) what is the most appropriate form of the fire property data, (2) what is the complete set of properties required, and (3) what predictive model is the most general.

An extension of the model presented by Cleary and Quintiere[7] will be described in this paper. It will demonstrate the way fire property data are required from ASTM E 1321 (ISO WD 5658 Part II) and E 1354 (ISO IS 5660), and will include the effect of thermal feedback

due to the increase of temperature within the room. These results will also be compared to the Swedish room-corner fire experiments.[8]

DESCRIPTION OF THE MODEL

The model simulates the ignition, flame spread, burn-out, and burning rate of wall and ceiling materials subject to a corner fire ignition source in a room. The flame pyrolysis and burn-out fronts are computed with respect to two modes of flame spread. One mode includes upward spread, spread along the ceiling, and spread along the wall-ceiling jet region. At this time, no distinction for these different configurations is made in the model and they are universally treated as governed by upward flame spread. The second mode of spread is composed of lateral spread along the wall and subsequent downward spread from the ceiling jet. Again, the same relationship will be considered for both. In this fashion, the pyrolysis and burn-out areas are computed.

The energy release rate per unit area is considered as a function of time. The energy release rate per unit area is governed by the flame heat flux and the radiative feedback from the heated room. Flame heat flux is considered uniform over the pyrolysis area, and uniform over the extended flame length. Two values are selected: $60\,kW/m^2$ over the pyrolysis area and associated with the square burner corner ignition flame, and $30\,kW/m^2$ for the extended flame spread which governs upward flame spread.

The room thermal feedback controls both the rate of spread through a computation of the material surface temperature ahead of the flame, and the rate of energy release per unit area through radiative heat transfer from the gas layer in the room. Global models are considered for room surface temperature and gas layer temperature. The radiative effects are considered to be maximized to give an upper limit for its effect. It appears that the thermal feedback effect is not significant compared to the flame heating effects until conditions representative of the onset of flashover, e.g. a gas temperature of 500 °C and a corresponding blackbody irradiance of $20\,kW/m^2$. Hence a more detailed representation of the room thermal feedback may not be productive at this time.

The details for each component of the analysis will be described in the following sections.

FIRE SCENARIO

The corner fire scenario considered in this analysis is based on tests described by Sundström.[8] A material lined the walls and ceiling of a

room 2·4 m × 3·6 m × 2·4 m high with a doorway opening 0·8 m × 2·0 m high. A square burner, 0·17 m on a side, located at the floor in a corner, subjected the wall to an ignition flame. The test scenario prescribed a 100 kW ignition flame for 10 min, followed by a 300 kW ignition flame. Each of 13 materials was examined up to flashover or burn-out under this ignition scenario. Flashover was experimentally identified as coinciding with 1 MW energy release rate from the room, and this will correspond to the flashover time computed in the situation.

IGNITION BURNER

The heights of the burner flame corresponding to 100 kW and 300 kW were modified from the process analysis by Cleary and Quintiere[7] to be 1·3 and 3·6 m respectively. The latter value corresponds to a correlation by Hasemi and Tokunaga[12] for corner burner fires. Their correlation gives a flame tip height of 1·9 m for the 100 kW fire compared with the 1·3 m value retained in the current simulation. A later analysis by Hasemi and Tokunaga[13] gives 2·8 m and 5·9 m for the flame tips and 2·1 m and 4·4 m for the continuous flame height corresponding to 100 kW and 300 kW for the 0·17 m square corner burner. These variations indicate the uncertainty, and suggest the need for additional study. Moreover, in the current situation, the flame length will be assumed to be representative of a vertical wall flame. The influence of a ceiling results in a flame extension in the model equal to the distance the representative wall flame is above the physical ceiling.

The burner is assumed to initially prescribe a uniform heat flux to the wall over a region defined by the flame height and the width of the burner. Based on a study by Williamson *et al.*,[14] the burner heat flux has been taken as 60 kW/m^2. In general, it appears that the burner flame heat flux depends on the size of the burner, the flame height or energy release rate, and the type of fuel supplied. Hence, a general simulation of room corner fires must be able to represent these effects. Moreover, the heat flux from the flames due to the burning surfaces in the corner and along the ceiling must also be predictable. At this time, only rational assumptions can be made for these heat fluxes.

IGNITION SIMULATION

The simulation model assumes a burner heat flux prescribed over a region of width (D), the burner side, and a flame height of 1·3 m for

the 100 kW ignitor. The surface temperature of the material is computed by[15]

$$T_{s,o} - T_{\infty} = \frac{1}{\sqrt{\pi k \rho c}} \int_0^t \frac{q(\tau)}{\sqrt{t-\tau}} \, d\tau \tag{1}$$

where $q(\tau) = \dot{q}''_{ig} + \sigma(T^4 - T^4_{s,o})$, $\dot{q}''_{ig}$ is the ignitor flame heat flux assumed at 60 kW/m^2 and T is the temperature of the upper gas layer in the room.

Blackbody radiation has been assumed with a configuration factor equal to one to maximize the room feedback effect. When $T_{s,o}$ equals the ignition temperature (T_{ig}), the time for ignition by the burner ($t_{ig,o}$) is found. At this time, the material begins to contribute energy and the flame spread process commences. Figure 1 indicates the path of flame extension from the burner and burning material. The ceiling jet region is approximated at a depth of 0·08H where H is the ceiling height. This

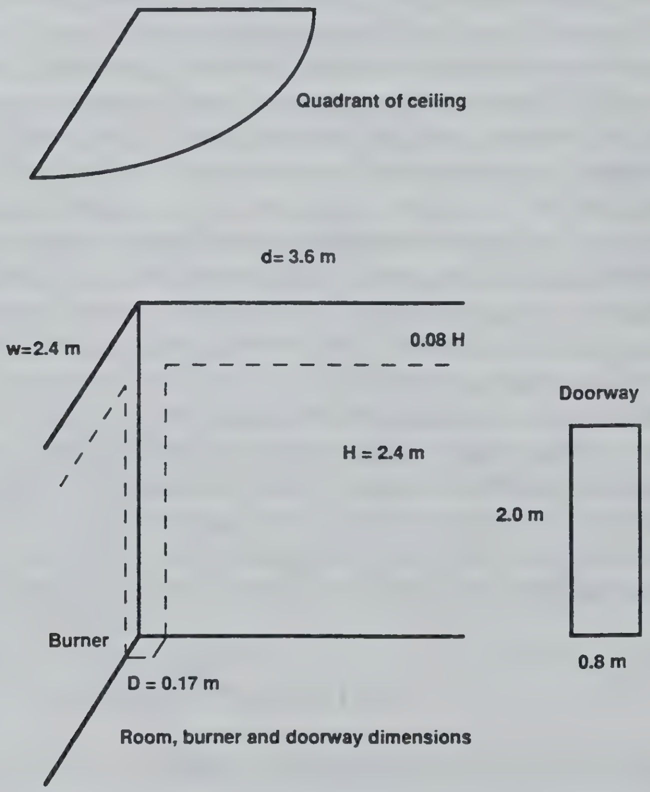


Fig. 1. Room and burner configuration. Dashed lines indicate path of upward flame extension.

is derived from Alpert's study of axisymmetric ceiling jets.[16] It is approximated as a constant depth because it varies slowly with distance from the fire source.

UPPER LAYER GAS TEMPERATURE

In general, the room gas and surface temperature vary with position and time, and are highly coupled with the energy release rate of the growing fire. Since it is expected that room thermal effects are not significant during early fire growth, the simplest representation for upper layer gas temperature is used. This eliminates the need for a comprehensive analysis by compartment zone or field models. However, the other aspects of the simulation model for fire growth could ultimately be incorporated into more comprehensive compartment fire models. The approach taken here is based on the compartment temperature correlation of McCaffrey *et al.*[17] with the coefficient modified for corner fires as done by Karlsson and Magnusson.[4] The correlation is given as

$$T = T_\infty\left\{1 + C\left[\frac{\dot{Q}}{\rho_\infty c_p\sqrt{g}\,T_\infty A_o\sqrt{H_o}}\right]^{2/3}\left[\frac{\sqrt{k\rho c/t}\,A_s}{\rho_\infty c_p\sqrt{g}\,A_o\sqrt{H_o}}\right]^{1/3}\right\} \tag{2}$$

where

$\dot{Q}$ is the total energy release rate
A_s is the room surface area
A_o is the area of the opening
H_o is the height of the opening
$k\rho c$ is the thermal inertia of the room lining materials
$\rho c_p\sqrt{g}$ is 3·44 kW/m$^{5/2}$—K
C is the coefficient taken as 2·2 for these corner fires (compared to 1·63 for room-centered fires)

The higher value of C is expected for corner fires compared to centered fires because of the lower entrainment rate of air into the corner fire. In other words, corner fires are hotter.

ENERGY RELEASE RATE

The total energy release rate is composed of the energy from the ignition burner and the energy from the wall and ceiling materials. This

is given by

$$\dot{Q}(t) = \dot{Q}_{ig} + \dot{Q}''A_p(t)$$

where $\dot{Q}_{ig}$ is the ignition burner energy release rate, $\dot{Q}''(t)$ is the energy release per unit area of the material and A_p is the pyrolysis area.

ENERGY FROM MATERIAL

The rate of energy release rate per unit area is assumed constant at any instant of time and uniform over the pyrolysis area. It is dependent on the net heat flux incident on the material which is composed of the flame heat flux, room thermal feedback flux, and the re-radiation loss assumed to occur at the ignition temperature of the material. The relationship for $\dot{Q}''$ is developed in terms of peak values of $\dot{Q}''$ found from the Cone Calorimeter for different irradiance levels (incident external radiant heat flux) as shown in Fig. 2. Peak values for $\dot{Q}''$ are denoted on the figure with some suggested degree of uncertainty. In Fig. 3, these peak values are plotted against the Cone irradiance level. The linear plot suggests that the net flame heat flux in the Cone Calorimeter is a constant. From the theory of burning rate, the slope is $\Delta H/L$ where ΔH is the heat of combustion and L is taken to be an effective heat of gasification. For the steady burning rate of liquid fuels,

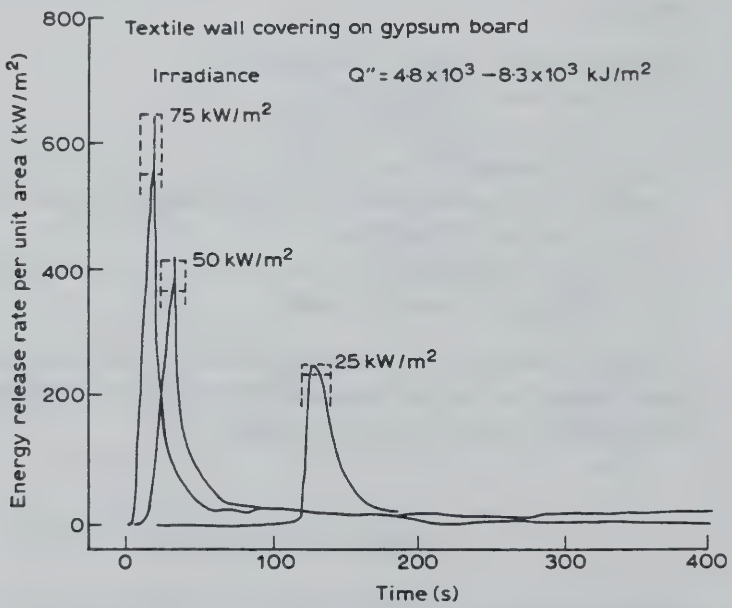


Fig. 2. Example of Cone Calorimeter data taken from Ref. 9.

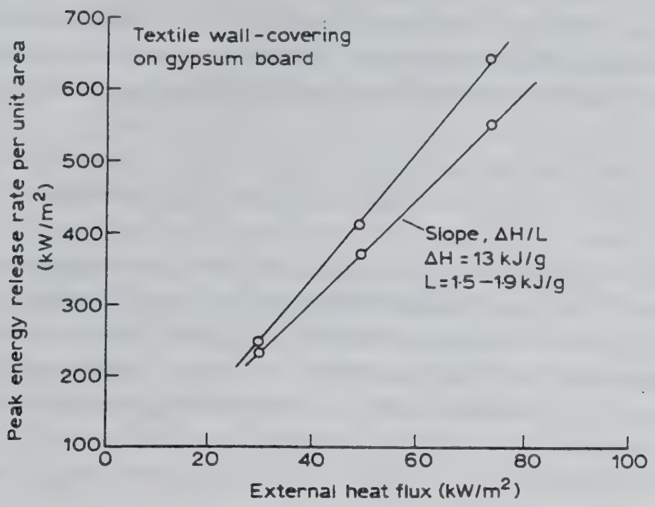


Fig. 3. Example of linear relationship between peak $\dot{Q}''$ and irradiance for Cone Calorimeter data.

L is a thermodynamic material property. Here, L is a modelling parameter that enables the determination of peak values of $\dot{Q}''$. Since the heat of combustion can be derived independently from the Cone Calorimeter by dividing the instantaneous energy release rate by the mass loss rate, the slope of the data in Fig. 3 can be used to determine L. In that example for the textile wall-covering on gypsum board, L is found to be 1·5 kJ/g for the absolute peak values of $\dot{Q}''$, but can range as high as 1·9 kJ/g if lower peak values are used.

If it is assumed that $\Delta H/L$ is an effective material property characteristic of the burning behavior which enables the computation of the peak values under all heat flux conditions, then

$$\dot{Q}'' = \frac{\Delta H}{L}(\dot{q}_f'' - \sigma T_{ig}^4 + \sigma T^4) \qquad (4)$$

where $\dot{q}_f''$ is the incident flame heat flux over the pyrolysis region (a specied constant), σT_{ig}^4 is the re-radiation flux loss, and σT^4 is the incident heat flux from the room, maximized as a blackbody gas with a configuration factor of one for all locations. As the compartment temperature, T, varies with time, the value for $\dot{Q}''$ varies with time.

Since the material initially burns due to the ignition burner flame, and the material flame heat flux is likely to be similar to the burner in its vicinity, 60 kW/m² is also assumed for $\dot{q}_f''$ here. As propagation moves far beyond the burner flame region, or to the ceiling or ceiling jet regions, some variations in $\dot{q}_f''$ are likely. Also this may depend on

the extent of the pyrolysis region. Such information on flame heat flux is not currently available. Hence, burning is assumed to occur based on the ignition burner flame heat flux for the entire pyrolysis region.

THE PYROLYSIS AREA, A_p

The pyrolysis area is computed from the configuration of the pyrolysis and burn-out fronts. Figure 4 illustrates a construction of the pyrolysis area as bounded between the pyrolysis and burn-out fronts. The pyrolysis front represents the position where pyrolysis has just begun; and the burn-out front represents the position where burn-out has just occurred. The initial pyrolysis area occurs at $t = t_{ig,o}$ for the region bounded by $y_{p,o} = 1{\cdot}3$ m, the burner flame height, and $x_{p,o} = 0{\cdot}17$ m, the

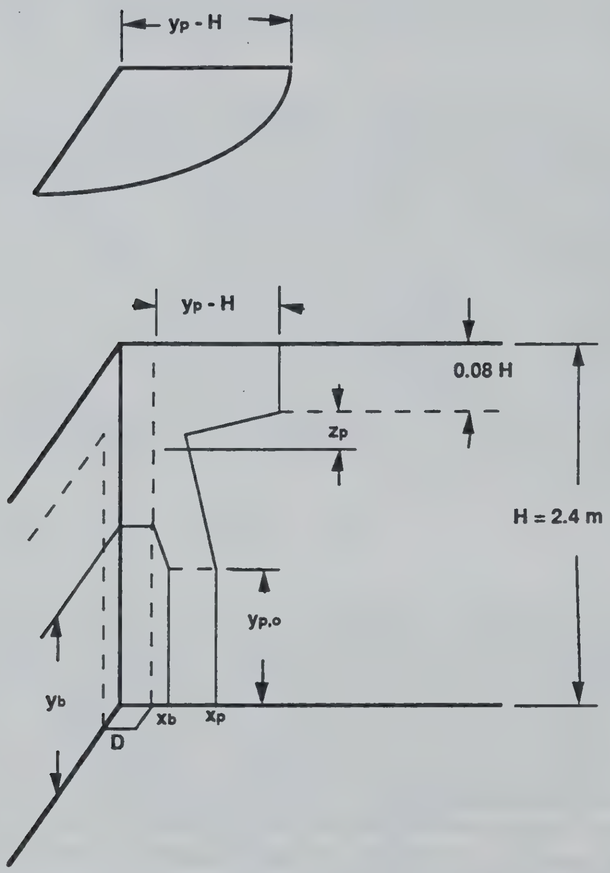


Fig. 4. Illustration of the pyrolysis and burn-out regions constructed from the pyrolysis and burn-out fronts.

dimension of the burner side. For the corner, this area is multiplied by 2 to account for the two symmetric walls. As spread and burn-out continues, Fig. 4 illustrates the upward spread pyrolysis front, y_p, to be greater than the room height. Consequently, it has been extended along the ceiling by a radius $y_p - H$, and along the wall–ceiling jet region by the same distance. The burn-out front associated with the upward spread component, y_b, is still less than the room height for this case. Corresponding pyrolysis and burn-out fronts for lateral spread are denoted by x_p and x_b respectively in Fig. 4. A downward pyrolysis front, z_p is also shown. It commences when $y_p = H$. The pyrolysis and burnout areas are formed by connecting the y-fronts to the x- and z-fronts by straight lines as shown in Fig. 4. The pyrolysis area is computed for the case shown in Fig. 4 as follows:

$$A_P = A_{P1} - A_{P2} + A_{PJ1} + A_{PC1} \tag{5}$$

where

$$A_{P1} = 2[Hx_{p,o} + (x_p - x_{p,o})y_{p,o} + (\tfrac{1}{2})(H - y_{p,o})(x_p - x_{p,o})]$$

$$A_{P2} = 2[y_p x_{p,o} + (x_b - x_{p,o})y_{p,o} + (\tfrac{1}{2})(y_b - y_{p,o})(x_b - x_{p,o})]$$

$$A_{PJ1} = 2[(y_b - H)(0{\cdot}08H) + (\tfrac{1}{2})(z_p)(y_p - H) - (\tfrac{1}{2})(0{\cdot}08H + z_p)^2(x_p - x_{p,o})/(H - y_{p,o})]$$

where the last term of A_{PJ1} is an approximation to the triangular overlap region

$$A_{PC1} = \min\,[(\pi/4)(y_p - H)^2,\ wd]$$

where wd is the area of the ceiling. Note that A_{P2} represents the burn-out area, A_{PJ1} is the wall pyrolysis area associated with the ceiling jet and A_{PC1} is the pyrolysis area for the ceiling.

The pyrolysis region can have various configurations depending on the values of the fronts. The complete set of configurations is given in the Appendix.

The differential equations governing the fronts will now be examined.

UPWARD FLAME SPREAD

The pyrolysis front y_p is applied to upward spread along the wall, the wall–ceiling jet, and the ceiling. It is assumed that a universal theory of upward flame spread governs all of these regions. As more sophistication is developed, more appropriate flame spread relationships could be applied. The governing equation is based on a constant flame heat flux

applied over the flame extension region beyond y_p whose initial temperature is T_s.[18]

$$\frac{dy_p}{dt} = \frac{y_f - y_p}{t_{ig}} \tag{6}$$

where

$$t_{ig} = \frac{\pi}{4} k\rho c \left[\frac{T_{ig} - T_s}{\dot{q}_f''}\right]^2$$

and

$$y_f = y_b + \begin{cases} k_f[\dot{Q}_{ig}' + \dot{Q}''(y_p - y_b)]^n, & y_b \le k_f \dot{Q}_{ig}'^n \\ k_f[\dot{Q}''(y_p - y_b)]^n, & y_b \ge k_f \dot{Q}_{ig}'^n \end{cases}. \tag{7}$$

T_s is the global room average surface temperature computed by eqn (1), but with

$$q(\tau) = \sigma(T^4 - T_s^4) + h_c(T - T_s) \tag{8}$$

and $h_c = 0{\cdot}01$ kW/m^{2}K as the convective heat transfer coefficient.

$\dot{q}_f''$ is the flame heat flux beyond the burning region. For vertical wall flame spread, this heat flux has been found to be 25 ± 5 kW/m^2 for flame extensions less than 2 m, and is relatively independent of the fuel.[18] Based on this, $\dot{q}_f''$ was specified as 30 kW/m^2 in the simulation.

y_f is the flame length in the upward or wind-aided direction. $\dot{Q}_{ig}'$ is the energy release rate for the burner which is equivalent to a line-source. It is determined, based on flame length, such that the burner flame length corresponding to $\dot{Q}_{ig}$ is equal to $k_f \dot{Q}_{ig}'^n$. The two possibilities for y_f indicated above either include the burner effect if y_b is less than or equal to the burner flame length, or it does not include the burner effect. In the latter case, the burner flame and the flame spreading on the wall material are not contiguous. The flame length for wall flames is given such that $k_f = 0{\cdot}067$ (m^5/kW^2)$^{1/3}$ and $n = \frac{2}{3}$, or approximately $k_f = 0{\cdot}01$ m^2/kW and $n = 1$.[18,19]

UPWARD BURN-OUT POSITION

The position of the burn-out front can be approximated by the difference equation

$$\frac{dy_b}{dt} \approx \frac{y_b(t + t_b) - y_b(t)}{t_b} \tag{9a}$$

but it can be shown that $y_b(t + t_b)$ is identical to $y_p(t)$ since burn-out will

occur at that position in the time interval t_b. Therefore

$$\frac{dy_b}{dt} \approx \frac{y_p(t) - y_b(t)}{t_b} \tag{9b}$$

gives the differential equation for the burn-out front where

$$t_b = Q''/\dot{Q}''$$

and Q'' is the total available energy per unit area which is assumed constant for a given material. It is determined by the area under the curves of the Cone Calorimeter data shown in Fig. 2.

LATERAL OR DOWNWARD SPREAD

The lateral pyrolysis position is determined by

$$\frac{dx_p}{dt} = \frac{\Phi}{k\rho c(T_{ig} - T_s)^2} \qquad \text{for } T_s \geq T_{s,min} \tag{10}$$

where Φ and $T_{s,min}$ are material dependent properties derived from the test procedure of ASTM E-1321.[6]

The downward pyrolysis position is given for $t > t_H$, the time when $y_p = H$ as

$$z_p = x_p(t) - x_p(t_H) \tag{11}$$

LATERAL OR DOWNWARD BURN-OUT

Based on the same logic as in developing eqn (9b),

$$\frac{dx_b}{dt} = \frac{x_p - x_b}{t_b} \tag{12}$$

and the downward burn-out front is given, as in eqn (11), by

$$z_b = x_b(t) - x_b(t'_H), \tag{13}$$

where t'_H is the time when $y_b = H$.

INITIAL CONDITIONS FOR THE FRONTS

For $0 \leq t < t_{ig,o}$:

$$y_p = x_p = 0$$

At $t = t_{ig,o}$ (ignition due to burner flame):

$$y_p = y_{p,o} = 1{\cdot}3 \text{ m}$$

$$x_p = x_{p,o} = 0{\cdot}17 \text{ m}$$

For $0 \leq t < (t_{ig,o} + t_{b,o})$:

$$y_b = x_b = 0$$

At $t = (t_{ig,o} + t_{b,o})$ (initial burning region extinguishes)

where

$$t_{b,o} = Q''/\dot{Q}''(t_{ig,o})$$

$$x_b = x_{p,o}$$

$$y_b = y_{p,o}$$

For $0 \leq t \leq t_H$

$$z_p = 0$$

and for $0 \leq t \leq t'_H$,

$$z_b = 0$$

These conditions constitute the values of the fronts over initial time periods, and the initial conditions for the differential equations.

SOLUTION METHODOLOGY

The equations to be solved constitute four ordinary differential equations, one integral equation, and one algebraic equation. They are summarized as follows:

eqn (6): $\dfrac{dy_p}{dt} = f_1(y_p, y_b, T, T_s)$

eqn (9b): $\dfrac{dy_b}{dt} = f_2(y_p, y_b, T)$

eqn (10): $\dfrac{dx_p}{dt} = f_3(T_s)$

eqn (12): $\dfrac{dx_b}{dt} = f_4(x_p, x_b, T)$

eqn (2): $T = f_5(T, y_p, y_b, x_p, x_b, t)$

eqn (1), (8): $T_s = f_6(T_s, T, t)$

First eqns (1) and (2) are solved until the burner ignites the wall material. Equation (1), the integral equation is integrated over the time steps using the Trapezoidal Rule, and a Gauss–Siedel iterative process is employed to obtain the new value of T_s. A Regula Falsi iterative method was required for eqn (2) to obtain consistent convergence for T.

Once ignition occurs the differential equations are integrated by a second order Runga–Kutta method, and the entire set are solved simultaneously advancing in time. Estimated values for T and T_s are used in determining the new values of the x and y variables, then these values are used to compute the new values for T and T_s.

In the simulation of the tests, the calculation is continued for 1000 s or until the total energy release rate reaches 2 MW. At 600 s, the burner ignition source is increased from 100 to 300 kW as prescribed in the scenario.

MATERIAL PROPERTY DATA

The material property data needed are displayed in Table 1 for the 13 materials tested. Most of these data were computed from various

TABLE 1
Flame Spread and Heat Release Properties of Swedish Fire Test Materials[a]

Material	T_{ig} (°C)	$k\rho c$ $(kW/m^2K)^2 s$	ϕ (kW^2/m^3)	$T_{s,min}$ (°C)	ΔH_c (kJ/g)	L (kJ/g)	Q''^{b} (kJ/m^2)
Particle board (PB)	405	0·626	8	180	14	5·4	$\geq 1{\cdot}2 \times 10^5$
Insulating fiberboard (IFB)	381	0·229	14	90	14	4·2	$\geq 6{\cdot}8 \times 10^4$
Medium density fiberboard (MDFB)	361	0·732	11	80	14	4·2	$\geq 10^5$
Wood panel (spruce) (WPS)	389	0·569	24	155	15	6·3	$\geq 1{\cdot}2 \times 10^5$
Melamine covered particle board (MELPB)	483	0·804	<1	435	11	4·8	$\geq 6{\cdot}0 \times 10^4$
Paper covered gypsum board (PAPGB)	388	0·593	0·5	300	10	4·8	$7{\cdot}2 \times 10^3$
PVC covered gypsum board (PVCGB)	410	0·208	25	300	13	3·7	$4{\cdot}6 \times 10^3$
Textile covered gypsum board (TEXGB)	406	0·570	9	270	13	1·5	$8{\cdot}3 \times 10^3$
Textile covered mineral wool (TEXMW)	391	0·183	6	174	25	2·8	$9{\cdot}3 \times 10^3$
Paper covered particle board (PAPPB)	426	0·680	13	250	13	6·5	$\geq 10^5$
Polyurethane foam (rigid) (PU)	393	0·031	3	105	13	3·1	$1{\cdot}4 \times 10^4$
Expanded polystyrene (EPS)	482	0·464	31[c]	~130[c]	28	1 5	$3{\cdot}2 \times 10^4$
Gypsum board (GP)	469	0·515	14	380	7	4·8	$2{\cdot}8 \times 10^3$

[a] From Refs 7 and 9 except as noted.
[b] Based on Cone data at 50 kW/m² irradiance.
[c] From Ref. 20.

sources by Cleary and Quintiere.[7] The current analysis developed the properties L and Q'' by analyzing the Cone Calorimeter data of Tsantaridis and Östman[9] as discussed relative to Figs 2 and 3. The accuracy of L and Q'' are limited due to the few available data points and the coarse approximation for integrating the curves. Consequently, a sensitivity analysis was conducted for some materials by varying L and Q'' from the 'base-line' values in Table 1, e.g. $0{\cdot}75\,L$ implies a value 0·75 of the baseline for L. It will be seen that thin materials, which have burning times of the order of 10 s, or Q'' values of 10^3 to 10^4 kJ/m², are very sensitive to variations in Q'' and L with respect to the flashover time produced.

TABLE 2
Time to Achieve a 1 MW Fire for the Swedish Room Tests

Material	*Experimental time (s)*	*Base-line (s)*	*1·25L (s)*	*1·25L/ 0·75Q″ (s)*	*1·25L/ 0·5Q″ (s)*	*0·75L (s)*
Particle board (PB)	157	121	167			88
Insulating fiberboard (IFB)	59	29	36			
Medium density fiberboard (MDFB)	131	91	120			
Wood panel (spruce) (WPS)	131	110	156			
Melamine covered particle board (MELPB)	465	222	295			
Paper covered gypsum board (PAPGB)	640	613	620	622	625	
PVC covered gypsum board (PVCGB)	611	30	38	42	602	
Textile covered gypsum board (TEXGB)	639	41	47	52	606	
Textile covered mineral wool (TEXMW)	43	12	14	14	14	
Paper covered particle board (PAPPB)	143	222	346			148
Rigid polyurethane foam (PU)	6	4	4			
Expanded polystyrene (EPS)	115	44	47			
Gypsum board (GB)	[a]	642	649	650	726 kW[a] 650 s	

[a] Did not reach 1 MW.

The property results tabulated in Table 1 were derived from several sources and in some cases data from two sources did not agree, hence decisions were made in favor of the most consistent data.[7] Sufficient data were not available for expanded polystyrene (EPS), so generic data were taken for Φ and $T_{s,min}$ from another source for completeness.[20] However, those data were for horizontal flame spread, and the unusually high Φ value may be due to a melting effect. It is not clear that this Φ would apply to the vertical case.

RESULTS

Simulations were run for all thirteen materials for the room-corner fire tests scenario.[8] Sensitivity analyses for variations in Q'' and L were performed for some materials. The results are tabulated in Table 2 and plotted in Fig. 5. Thick homogeneous materials yield predicted flashover times (times to reach 1 MW) generally lower but within 50% of the experimental values. For the variables in L and Q'' used (±25%), the predicted accuracy is still within 50%. The Melamine covered Particle Board (MELPB) burned in two modes due to the laminated construction and has a large time difference between the predicted and experimental values. The uniform burning assumption used in the model may be too crude for the actual burning variations of this combustible composite.

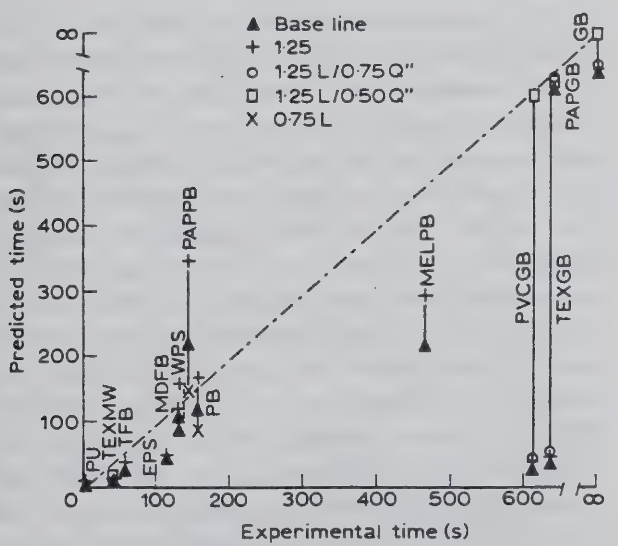


Fig. 5. A comparison of the predicted flashover times with the experimental times to reach 1 MW.

The Paper covered Particle Board (PAPPB) is another example of a combustible composite that presents a challenge in modeling its burning behavior. The expanded polystyrene melts and spills over the floor which influences the flashover time, and the melting effect is not addressed at all in the model.

The thin materials on inert substrates display an interesting effect. In most cases, flashover did not occur until after the 300 kW burner level was initiated in the test. However, the simulated results for PVC covered Gypsum Board, Textile covered Gypsum Board, and Gypsum Board are only consistent with the experimental results for $1{\cdot}25L$ and $0{\cdot}5Q''$ input data as seen in Table 2. Other values of Q'' and L yielded earlier flashover times.

These variations in flashover times associated with relatively small changes in the input data are due to the tendency of upward flame spread to accelerate or decelerate. From the linearized theory discussed by Cleary and Quintiere,[7] the parameter

$$b = k_f\dot{Q}'' - 1 - t_{ig}/t_b \tag{14}$$

controls acceleration, leading to acceleration if $b > 0$ and ultimate extinction if $b < 0$. In the current simulation, b varies with time and for b near zero, small perturbations in the input data can lead to big differences in fire growth. A material having a b near zero may not appear to give repetitively consistent results even in actual full-scale fire testing.

It should be noted that for these materials studied, fire growth due to lateral spread was not a significant factor until the onset of flashover. The relatively low flame spread rate, and the need to achieve a minimum surface temperature ($T_{s,min}$) before spread could commence are reasons for its lack of significance in this simulation model. It may be argued that an improved radiative exchange model for the corner fire might lead to more significant lateral flame spread effects, but enhanced radiation due to the corner flames is countered by the maximized gas layer radiation assumed in the model.

Figure 6a through 6d show the nature of fire growth for the Textile on Gypsum Board for case $0{\cdot}5Q''/1{\cdot}25L$. In Fig. 6c, the fire appears headed for extinction, but when the 300 kW burner fire is initiated at 600 s, its flame extends beyond the pyrolysis region in the ceiling jet. This causes acceleration of the pyrolysis front and flashover. Figure 7 shows the corresponding predicted rate of energy release compared to both the base-line data input and the experimental results. The predicted time for ignition and initial rate of spread are faster than the experimental results. The sensitivity to flashover with Q'' and L is

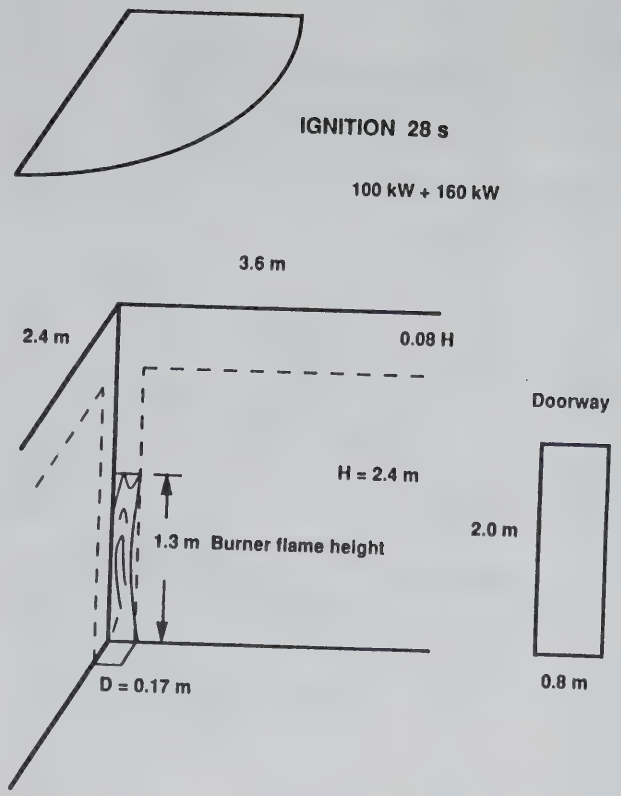


Fig. 6a. Textile covered gypsum board. Ignition at 28 s.

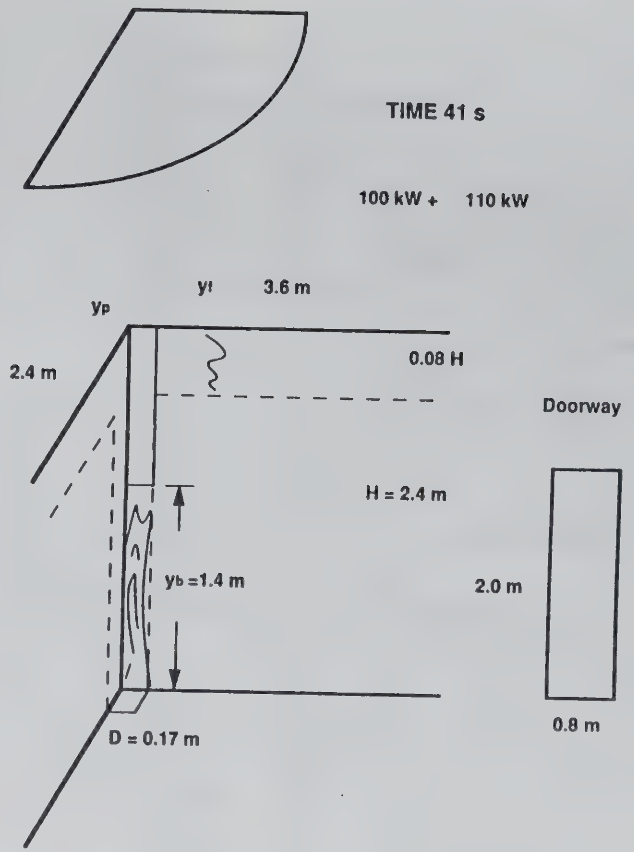
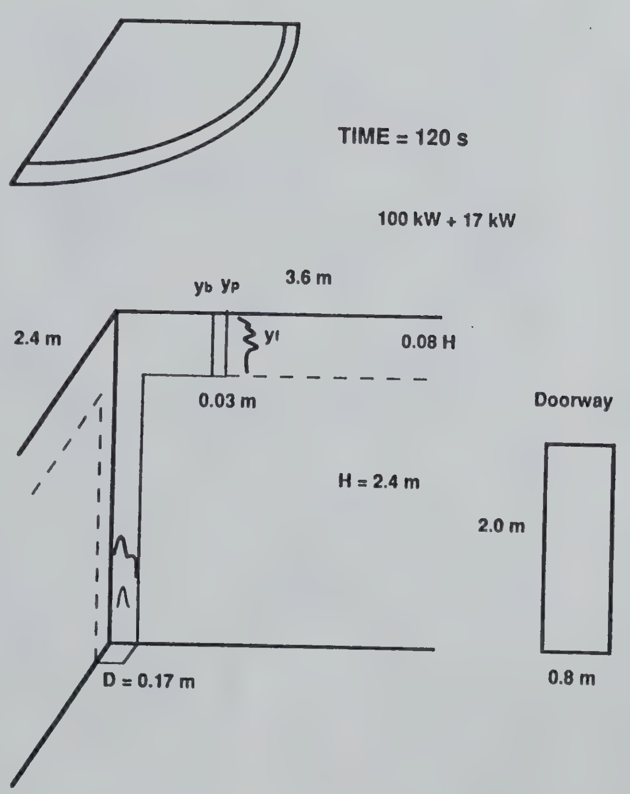


Fig. 6b. Textile covered gypsum board. Flame spread at 41 s.



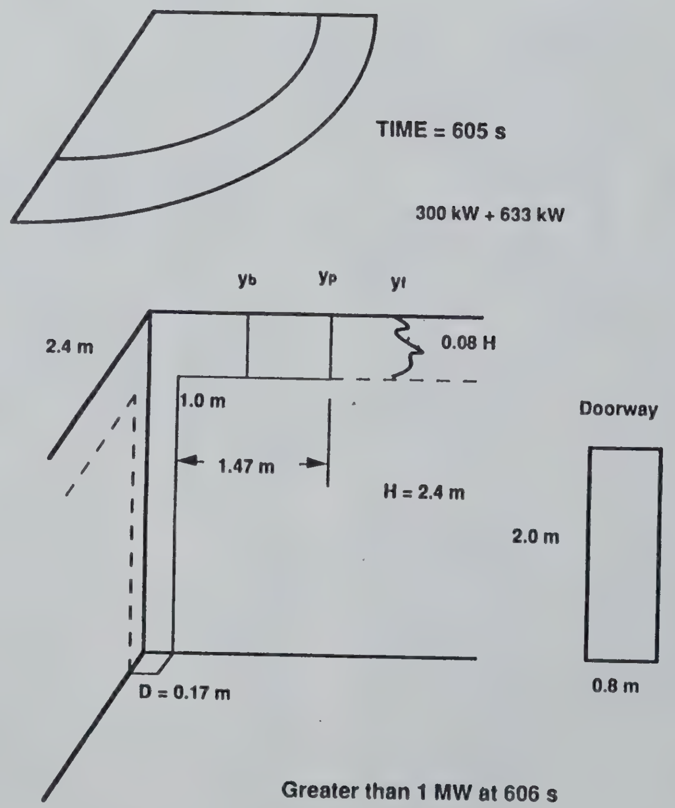


Fig. 6c. Textile covered gypsum board. Flame spread at 120 s. **Fig. 6d.** Textile covered gypsum board. Just before flashover at 1 MW.

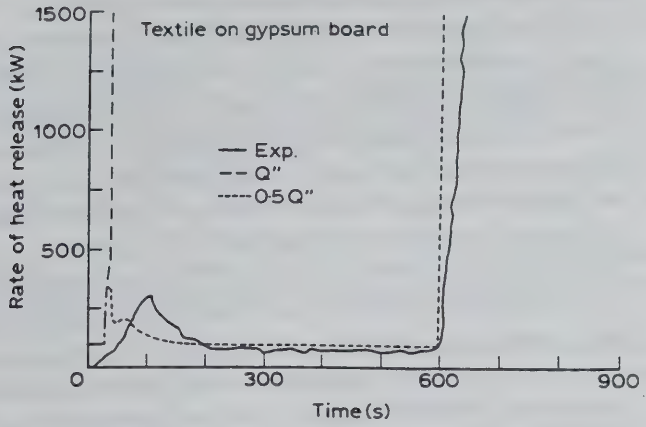


Fig. 7. Comparison of predicted energy release rates with experiments results for textile covered gypsum board.

apparent. This is also seen for Gypsum Board in Fig. 8. The base-line case leads to flashover while the $0{\cdot}5Q''/1{\cdot}25L$ case only achieves about 750 kW compared with 500 kW for the experimental result.

CONCLUSIONS

A simulation model has been developed that successfully addresses fire growth on walls and ceiling materials in a room corner-fire scenario. All modes of fire spread are modeled approximately, but validated ceiling

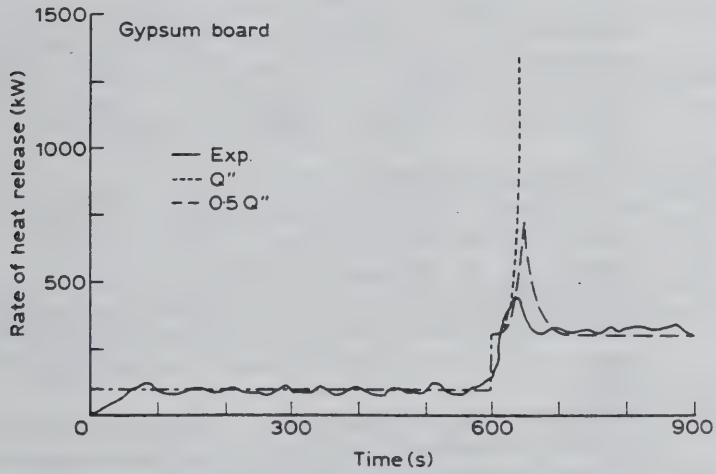


Fig. 8. Comparison of predicted energy release rates with experimental results for gypsum board.

and wall–ceiling jet flame spread models need to be developed. Assumptions have been made based on limited information for flame heat transfer rates to cause burning and spread, and more complete experimental results are needed. A technique has been included to use Cone Calorimeter data in the model by representing the rate of energy release per unit area as a peak value over a burn time interval in terms of properties Q'' and L. However relatively small variations in these properties can have a significant effect on fire growth for especially thin combustible materials. Overall, the simulation model executed for the 13 tests yielded fair to good results in predicting flashover. In general, the simulation model offers (1) an illustration of how to use fire property data for prediction fire growth scenarios, (2) a basis for elucidating needed research for improving fire growth models, and (3) a preliminary basis for assessing the fire hazard of materials.

ACKNOWLEDGEMENTS

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APPENDIX: PYROLYSIS AREA FORMULAS

(1) $t_{ig,o} \leq t \leq t_{ig,o} + t_{b,o}$: The ignitor burner has caused ignition of region $(x_{p,o}, y_{p,o})$ but has not burned out yet.

(a) And $y_p < H$, (only the wall is pyrolyzing, Fig. A1a):

$$A_p = 2[y_P x_{p,o} + (x_p - x_{p,o})y_{p,o} + 0{\cdot}5(y_p - y_{p,o})(x_p - x_{p,o})] \quad \text{(A1)}$$

(b) Or $y_p \geq H$, (wall and ceiling is pyrolyzing, Fig. A1b):

$$A_{P1} = 2[Hx_{p,o} + (x_p - x_{p,o})y_{p,o} + 0{\cdot}5(x_p - x_{p,o})(H - y_{p,o}) \quad \text{(A2)}$$

$$z_p = x_p - x_p(t_H) \quad \text{(A3)}$$

$$A_{PJ1} = 2\Bigg[(y_p - H)(0{\cdot}08H) + \tfrac{1}{2}z_p(y_p - H) \underbrace{- \tfrac{1}{2}(0{\cdot}08H + z_p)^2\left(\frac{x_p - x_{p,o}}{H - y_{p,o}}\right)\Bigg]}_{\text{approx. overlap correction}}, \qquad z_p > 0 \quad \text{(A4)}$$

or

$$A_{PJ1} = 2(y_P - H)(0{\cdot}08H), \qquad z_p = 0 \quad \text{(A5)}$$

$$A_{PC1} = \min\{(\pi/4)(y_p - H)^2, wd\} \quad \text{(A6)}$$

$$A_p = A_{P1} + A_{PJ1} + A_{PC1} \quad \text{(A7)}$$

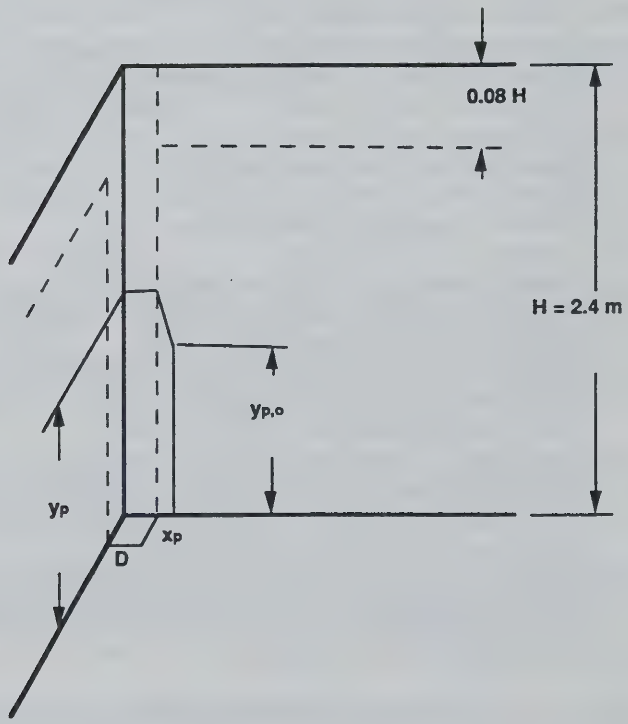

Fig. A1a. $t_{ig,o} \leq t \leq t_{ig,o} + t_{b,o}$ and $y_p < H$.

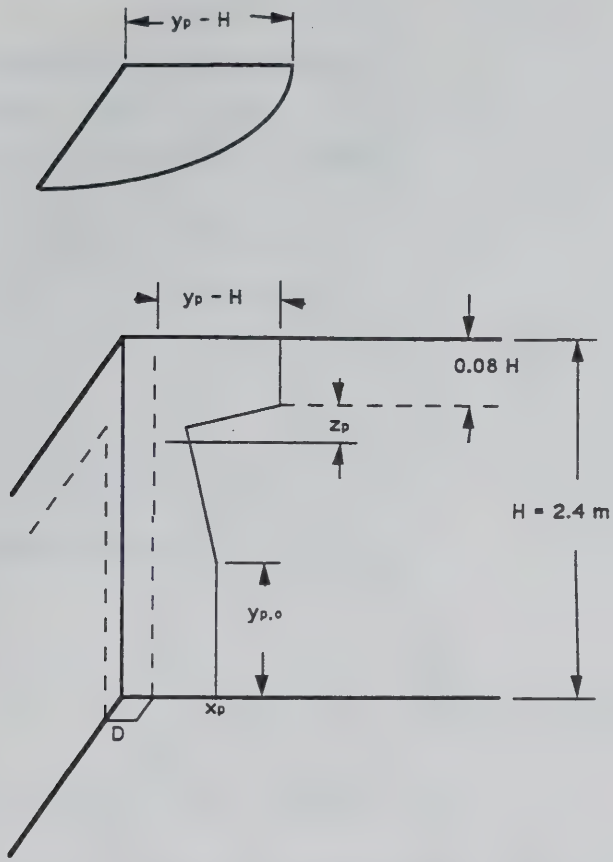

Fig. A1b. $t_{ig,o} \leq t \leq t_{ig,o} + t_{b,o}$ and $y_p \geq H$.

(2) $t > t_{ig,o} + t_{b,o}$ (the ignitor region has burned out and a burn-out region (y_b, x_b) is now computed):

(a) And $y_p \leq H$ (only the wall is burning, Fig. A2a):

$$A_{P1} = 2[y_p x_{p,o} + (x_p - x_{p,o})y_{p,o} + 0{\cdot}5(y_p - y_{p,o})(x_p - x_{p,o})] \quad \text{(A8)}$$

$$A_{P2} = 2[y_b x_{p,o} + (x_b - x_{p,o})y_{p,o} + 0{\cdot}5(y_b - y_{p,o})(x_b - x_{p,o})] \quad \text{(A9)}$$

$$A_P = A_{P1} + A_{P2} \quad \text{(A10)}$$

(b) Or $y_p > H, y_b \leq H$ (ceiling is pyrolyzing, but has not burned out yet) (see Fig. 4):

$$A_{P1} = 2[Hx_{p,o} + (x_p - x_{p,o})y_{p,o} + 0{\cdot}5(H - y_{p,o})(x_p - x_{p,o})] \quad \text{(A11)}$$

$$A_{P2} = 2[y_b x_{p,o} + (x_b - x_{p,o})y_{p,o} + 0{\cdot}5(y_b - y_{p,o})(x_b - x_{p,o})] \quad \text{(A12)}$$

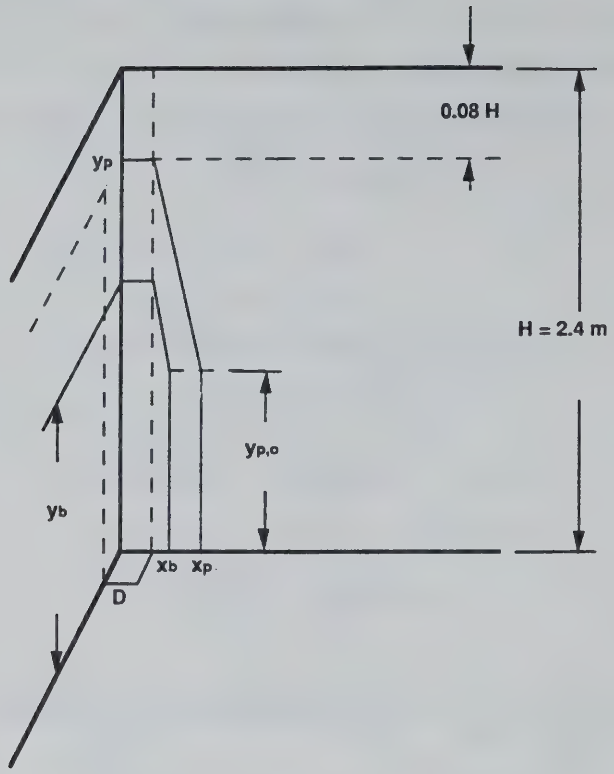

Fig. A2a. $t > t_{ig,o} + t_{b,o}$ and $y_p \leq H$.

$$A_{PJ1} = 2\Big[(y_p - H)(0{\cdot}08H) + \tfrac{1}{2}z_p(y_p - H) - \underbrace{\tfrac{1}{2}(0{\cdot}08H + z_p)^2\Big(\frac{x_p - x_{p,o}}{H - y_{p,o}}\Big)}_{\text{approx. overlap correction}}\Big], \qquad z_p > 0 \quad \text{(A13)}$$

or

$$A_{PJ1} = 2(y_p - H)(0{\cdot}08H), \qquad z_p = 0 \quad \text{(A14)}$$

$$A_P = A_{P1} - A_{P2} + A_{PJ1} + A_{PC1} \quad \text{(A15)}$$

(c) $y_p > H$, $y_b > H$ (wall and ceiling have burn-out regions, Fig. A2c):

$$A_{P1} = 2[Hx_{p,o} + (x_p - x_{p,o})y_{p,o} + 0{\cdot}5(x_p - x_{p,o})(H - y_{p,o})] \quad \text{(A16)}$$

$$A_{P2} = 2[Hx_{p,o} + (x_b - x_{p,o})y_{p,o} + 0{\cdot}5(H - y_{p,o})(x_b - x_{p,o})] \quad \text{(A17)}$$

A_{PJ1} = by eqns (A13) and (A14)

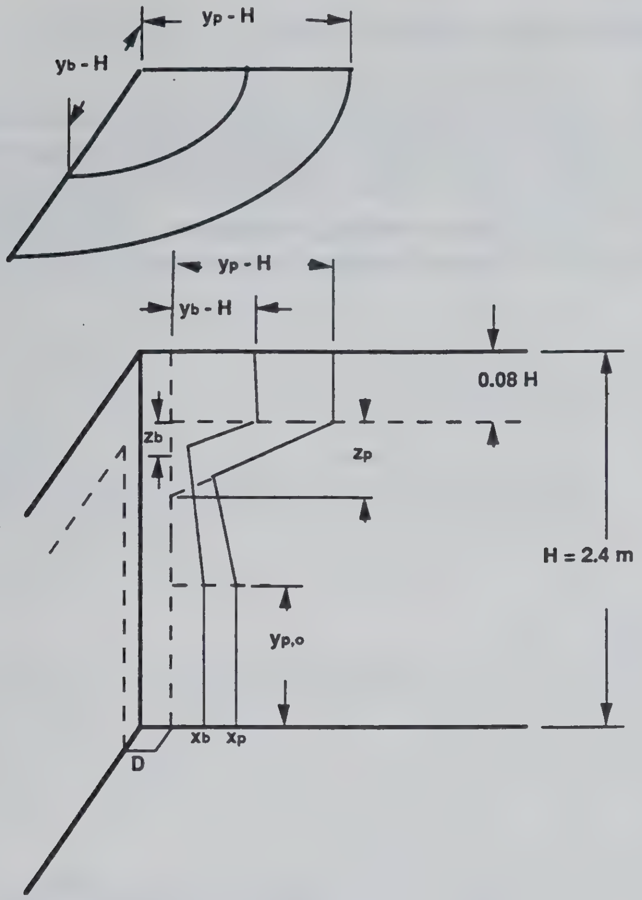

Fig. A2c. $t > t_{ig,o} + t_{b,o}$ and $y_p > H$, $y_b > H$.

$$z_b = x_b - x_b(t'_H) = x_b - x_{b,H} \tag{A15}$$

$$A_{PJ2} = 2\left[(y_b - H)(0{\cdot}08H) + \tfrac{1}{2}z_b(y_b - H) - \tfrac{1}{2}(0{\cdot}08H + z_b)^2\left(\frac{x_b - x_{p,o}}{H - y_{p,o}}\right)\right], \qquad z_b > 0 \tag{A16}$$

or

$$A_{PJ2} = 2(y_b - H)(0{\cdot}08H), \qquad z_b = 0 \tag{A17}$$

$$A_{PC12} = \min\{(\pi/4)[y_p - H)^2 - (y_b - H)^2], [wd - \pi/4(y_b - H)^2]\} \tag{A18}$$

$$A_P = A_{P1} - A_{P2} + A_{PJ1} - A_{PJ2} + A_{PC12} \tag{A19}$$

D.2—Fire Growth Model Source Code

The FORTRAN source code for Quintiere's fire growth model is presented below. The code used for the analysis in this report is slightly different from the code listed in other reports. Changes to the code were made in order to provide a more robust filename management, provide more user defined ignition burner output parameters and to increase the accuracy of the main program loop. Most of the changes are listed in the source code with the following: [SED]

```
c  *********************************************************************
c       PROGRAM:  Fire Growth Model
c       VERSION:  1.2
c       AUTHOR:   Dr. James Quintiere, University of Maryland,
c                 Department of Fire Protection Engineering
c       REVISION: Currently being revised by S. E. Dillon
c       DATE:     11-26-97
c  *********************************************************************

      IMPLICIT REAL (a-z)
      INTEGER NMAX, n, burntime, lengthfilename, qburn, qtime, qwidth
      CHARACTER MATNAME*40, name*12
      CHARACTER*1filename(12)
c     Changed the maximum time to 3600 from 1300.
      PARAMETER (NMAX = 3600)
      PARAMETER (PI = 3.14159, SB = 5.66E-11)
c       SB = Stefan-Boltzman constant
      DIMENSION yp(NMAX), yb(NMAX), xp(NMAX), xb(NMAX), t(NMAX),
     *  ts(NMAX), time(NMAX), ts0(NMAX), ap(NMAX), qburn(NMAX),
      *  qtime(NMAX), qwidth(NMAX)

c          VARIABLES
c          ---------
c qig      Ignitor energy release rate in kW
c qigw     Ignitor energy per width in kW/m (based on flame height [SED])
c qa         Total heat release from the pyrolysis area
c q        Total heat release {qa*ap + qig}
c yf       Flame length
c yp(),    Vertical pyrolysis position
c yb(),    Vertical burnout position
c xp(),    Lateral half-width pyrolysis position
c xb(),    Lateral half-width burnout position
c t(),     Gas temperature
c ts(),    Surface temperature
c ts0(),   Surface temperture due to ignition
c time(),  Time from inception of ignition
c ap(),    Pyrolysis area
c HCONV(), CONVECTIVE HEAT TRANSFER COEFFICIENT (kW/m**2 K)
c User input data ('filename'.in):
c MATNAME   MATERIAL NAME OR ID (40 CHARACTERS MAX.)
c tinf      Ambient temperature in Deg. K
c c1        Gas parameter
c xrc       Thermal inertia (k*rho*c)
c h0        Vent height in m
c w0        vent width in m
```

```
c yp0       Height of ignition region in m
c xp0       Half-width of ignition region in m
c qnum        The number of heat flux levels for the ignitor burner  [SED]
c qburn()   The ignitor heat flux levels (replaces qig) [SED]
c qwidth()  Ignitor energy per width in kW/m: (replaces qigw)  [SED]
c qtime()     The times associated with each ignitor heat flux  [SED]
c as        Surface area of room in m**2
c qfnet     Flame net heat flux in kW     {(qflxig)-[SB*(tig)**4]}
c hc        Heat of combustion in kJ/g
c xl        Heat of gasification in kJ/g
c qrfig     Configuration radiative incident heat flux in kW/m**2
c tol       Tolerance on iterations
c r         Parameter for ceiling area (r = 2, wall; r = 4, ceiling)
c qflxig    Ignitor incident heat flux in kW/m**2
c c2        Flame length coefficient
c c3        Flame length power
c c4        Total energy per unit area in kJ/m**2
c tig       Ignition temperature in Deg. K
c phi       Lateral flame spread parameter
c h         Room height in m
c w         Room width in m
c d         Room depth in m
c qf        Incident flame heat flux in spread in kW/m**2
c qmax      Maximum fire size, stops run in kW
c tsmin     Minimum temperature for spread in Deg. K
c dtime     Time step in Sec.
c endtime   Maximum run time for the model (sec) [SED]


c     MAIN PROGRAM - Fire growth on room surfaces
c     -------------------------------------------
c     Input user determined parameters
c     Please note - this input routine is a bare bones, quick and dirty
c                   method to input data for use while developing the
c                   algorythms.
c     Read the 'filename'.IN to be used  [SED].
       WRITE(*,*)
       WRITE(*,*)'FLAME SPREAD MODEL: Version 1.2'
       WRITE(*,*)'-------------------------------'
       WRITE(*,*)'Press <RETURN> to exit.'
   20  WRITE(*,*)
       WRITE(*,*)
       WRITE(*,*)'Enter "filename":'
       READ(*,25) (filename(i), i=1,8)
   25  FORMAT(8a1)
c     Determine the length of 'filename'  [SED].
      DO 30 I=8,1,-1
      IF (filename(I).NE.' ') GOTO 35
      IF (I.EQ.1) GOTO 5000
   30 CONTINUE
   35 lengthfilename = I
c     Open the input file  [SED].
      CALL FILE(filename,lengthfilename,'.in',3,name)
      OPEN (1,FILE=name,STATUS='OLD',ERR=2000)
c     Read the data from the input file.
      READ(1, 50) MATNAME
      READ(1, *) tinf
```

```
      READ(1, *) c1
      READ(1, *) xrc
      READ(1, *) h0
      READ(1, *) w0
      READ(1, *) yp0
      READ(1, *) xp0
        READ(1, *) qnum
      DO 45 n = 1, qnum
            READ(1,40) qburn(n),qwidth(n),qtime(n)
   40 FORMAT (3i7)
   45 CONTINUE
      READ(1, *) as
      READ(1, *) qfnet
      READ(1, *) hc
      READ(1, *) xl
      READ(1, *) qrfig
      READ(1, *) tol
      READ(1, *) r
      READ(1, *) qflxig
      READ(1, *) c2
      READ(1, *) c3
      READ(1, *) c4
      READ(1, *) tig
      READ(1, *) phi
      READ(1, *) h
      READ(1, *) w
      READ(1, *) d
      READ(1, *) qf
      READ(1, *) qmax
      READ(1, *) tsmin
      READ(1, *) dtime
      READ(1, *) endtime
      CLOSE(1)

c     Initialized variables:
c     Time from aplication of ignitor
      time(1) = 0
c     Room gas temperature in Deg. K
      t(1) = 293.0
c     Avg. room surface temperature in Deg. K
      ts(1) = 293.0
c     Surface temperature due to ignitor in Deg. K.
      ts0(1) = 293.0
c     Pyrolysis area in m**2
      ap(1) = 0.0
c     Pyrolysis front vertical coordinate in m
      yp(1) = 0.0
c     Burnout vertical coordinate in m
      yb(1) = 0.0
c     Lateral pyrolysis coordinate in m
      xp(1) = 0.0
c     lateral burnout coordinate in m
      xb(1) = 0.0
c      The ignitor burner heat flux level counter (1 = initial)
      burntime = 1
c     Energy release rate in kW
      qig = qburn(burntime)
```

```
      qigw = qwidth(burntime)
      q = qig
c     Index
      kount = 0
c     Index
      kyp = 0
      kyb = 0
c     Ceiling jet dummy values
      xph = 0.
      xbh = 0.
c     Ignitor ignition time with no heating in Sec.
      tmig0 =  1.E06

c     Open the output file
      CALL FILE(filename,lengthfilename,'.out',4,name)
      OPEN (1,FILE=name,STATUS='UNKNOWN')
      WRITE(1, 50) MATNAME
      WRITE (1, *) "time(s)   yp(m)   xp(m)   yb(m)   xb(m)   ap",
     *             "(m^2)   t(K)     ts(K)      q(kW)"
      WRITE (1, 1000) time(1), yp(1), xp(1), yb(1),xb(1), ap(1),
     *                  t(1), ts(1), q
   50 FORMAT (A40)


c     MAIN LOOP
c     ---------
c     Advance Time
      DO 100 n = 1, endtime
c           Increase time step
          time(n + 1) = time(n) + dtime
c     Does the ignition burner need to be adjusted? [SED].
      IF (time(n + 1) .EQ. qtime(burntime)) THEN
c         Ignition burner is adjusted based on the input file [SED]
          burntime = burntime + 1
          qig = qburn(burntime)
          qigw = qwidth(burntime)
c         Has the maximum burner time been reached?
          IF (burntime .GT. qnum) THEN
c                 Ignition fire is turned off
              qig = 0.
              qigw = 0.
          END IF
      END IF
c     Does Ignition Occur?
      IF (time(n + 1) .LT. tmig0) THEN
c           Set burn region to zero
            yp(n + 1) = 0.
            xp(n + 1) = 0.
            yb(n + 1) = 0.
            xb(n + 1) = 0.
            ap(n + 1) = 0.
c           Compute room gas temperature due to ignitor
            CALL Gtemp(t(n + 1), t(n), ap(n + 1), time(n + 1),
     *              hc, xl, qfnet, qrfig, qig, tinf, w0, h0, as,
     *              xrc, cl, tol)
c           Compute room surface temperature
            CALL Stemp(ts,t,time,dtime,0.,0.01,xrc,tinf,tol,n,NMAX)
```

```
c           Compute surface temperature at ignitor
            CALL Stemp(ts0,t,time,dtime,qflxig,0.0,xrc,tinf,tol,n,NMAX)
c           Does ignition Occur?
            IF (ts0(n + 1) .GE. tig) THEN
c              Record ignition time.
               tmig0 = time(n + 1)
c                Compute the energy release rate per unit area (kW/m^2)
               qa = (hc/xl) * (qfnet + qrfig + sb * t(n + 1)**4)
c              Compute initial burnout time.
               tmb0 = c4/qa
c              Set initial values of pyrolysis region
               yp(n + 1) = yp0
               xp(n + 1) = xp0
               yb(n + 1) = 0.
               xb(n + 1) = 0.
               ap(n + 1) = 2. * xp0 * yp0
            ELSE
               GOTO 410
            END IF
      ELSE


200         CONTINUE
c           Controls burn calculations
c           --------------------------
            IF (time(n + 1) .GT. (tmig0 + tmb0)) THEN
250            CONTINUE
c              Ignitor burnout has occurred.
c              This section computes burnout fronts (yb & xb) as
c              well as pyrolysis fronts (yp & xp) for n+1 by
c              Runge Kutta
c
c              Set initial conditions for  yb and xb
               kount = kount + 1
               IF (kount .EQ. 1) THEN
                  yb(n) = yp0
                  xb(n) = xp0
               END IF

260            CONTINUE
c              Calculate YPE
               CALL F1(f11, yp(n), yb(n), t(n), ts(n),
     *            hc, xl, qfnet, qrfig, c2, c3, qigw, xrc, tig, qf)
               ype = yp(n) + f11 * dtime
c              Is the surface temperature less than what is needed
c              for lateral flame spread.
               IF (ts(n) .LE. tsmin) THEN
c                       No lateral flame spread
                  xpe = xp0
                  xbe = xp0
               ELSE
c                 Calculate lateral flame spread
                  CALL F3(f31, ts(n),
     *                    xrc, tig, phi)
                  xpe = xp(n) + f31 * dtime
                  CALL F4(f41, xp(n), xb(n), t(n),
     *                    hc, xl, qfnet, qrfig, c4)
```

```
            xbe = xb(n) + f41 * dtime
         END IF
c        Calculate ybe and ape
         CALL F2(f21, yp(n), yb(n), t(n),
     *           hc, xl, qfnet, qrfig, c4)
         ybe = yb(n) + f21 * dtime
         CALL Area(ape, ype, ybe, xpe, xbe, yp0, xp0, h, w, d,
     *            r, tmig0, tmb0, time(n + 1), xph, xbh)
         CALL Gtemp(te, t(n), ape, time(n + 1), hc, xl, qfnet,
     *              qrfig, qig, tinf, w0, h0, as, xrc, c1, tol)
c        Estimated gas temperature in iteration
         t(n + 1) = te
         CALL Stemp(ts,t,time,dtime,0.,0.01,xrc,tinf,tol,n,
     *              NMAX)
c        Estimated surface temperature in iteration
         tse = ts(n + 1)
c        Complete Runga-Kutta for yp, yb, xp and xb
         CALL F1(f12, ype, ybe, te, tse,
     *          hc, xl, qfnet, qrfig, c2, c3, qigw, xrc, tig, qf)
         yp(n + 1) = yp(n) + (f11 + f12) * dtime / 2.
         CALL F3(f32, tse,
     *           xrc, tig, phi)
         xp(n + 1) = xp(n) + (f31 + f32) * dtime / 2.
         CALL F2(f22, ype, ybe, te,
     *           hc, xl, qfnet, qrfig, c4)
         yb(n + 1) = yb(n) + (f21 + f22) * dtime / 2.
         CALL F4(f42, xpe, xbe, te,
     *           hc, xl, qfnet, qrfig, c4)
         xb(n + 1) = xb(n) + (f41 + f42) * dtime / 2.
      ELSE


300      CONTINUE
c        Ignitor burnout has not occurred
c        This section computes yp and xp
c        by a second order Runge Kutta method

c        Set burnout region to zero
         yb(n + 1) = 0.
         xb(n + 1) = 0.
c        Compute estimated  (ype)
         CALL F1(f11, yp(n), yb(n), t(n), ts(n),
     *          hc, xl, qfnet, qrfig, c2, c3, qigw, xrc, tig, qf)
         ype = yp(n) + f11 * dtime
c        Compute estimated (xpe) or fixed xp
         IF (ts(n) .LE. tsmin) THEN
c              No lateral flame spread
            xpe = xp0
         ELSE
c              Calculate xpe
            CALL F3(f31, ts(n), xrc, tig, phi)
            xpe = xp(n) + f31 * dtime
         END IF
c        Compute estimated pyrolysis area (aps)
         CALL Area(ape, ype, yb(n + 1), xpe, xb(n + 1), yp0, xp0,
     *            h, w, d, r, tmig0, tmb0, time(n + 1), xph, xbh)
c        Compute estimated gas temperature (te)
```

```
              CALL Gtemp(te, t(n), ape, time(n + 1), hc, xl, qfnet,
     *                  qrfig, qig, tinf, w0, h0, as, xrc, c1, tol)
c             Compute estimated surface temperature (tse)
              t(n +1) = te
              CALL Stemp(ts,t,time,dtime,0.,0.01,xrc,tinf,tol,n,
     *                  NMAX)
              tse = ts(n + 1)
c             Compute yp(n + 1)
              CALL F1(f12, ype, yb(n + 1), te, tse,
     *              hc, xl, qfnet, qrfig, c2, c3, qigw, xrc, tig, qf)
              yp(n + 1) = yp(n) + (f11 + f12) * dtime / 2.
c             compute xp(n + 1)
              CALL F3(f32, tse,
     *               xrc, tig, phi)
              xp(n + 1) = xp(n) + (f31 + f32) * dtime / 2.
           END IF


400        CONTINUE
c     Check if yp and yb have reached ceiling
c     Compute values xph and xbh
      IF (yp(n+1) .GE. h) THEN
         kyp = kyp +1
      END IF
      IF (kyp .EQ. 1) THEN
         xph = xp(n+1)
      END IF
      IF (yb(n+1) .GE. h)  THEN
         kyb = kyb + 1
      END IF
      IF (kyb .EQ. 1)  THEN
         xbh = xb(n+1)
      END IF
c          Compute ap, t, q, ts, at (n + 1)
           CALL Area(ap(n + 1), yp(n + 1), yb(n + 1), xp(n + 1),
     *            xb(n + 1), yp0, xp0, h, w, d, r, tmig0, tmb0,
     *            time(n + 1), xph, xbh)
           CALL Gtemp(t(n + 1), t(n), ap(n + 1), time(n + 1), hc, xl,
     *               qfnet, qrfig,
     *               qig, tinf, w0, h0, as, xrc, c1, tol)
           CALL Stemp(ts, t, time, dtime, 0., 0.01,xrc,tinf,tol,n,
     *               NMAX)
           IF (ts(n + 1) .LE. tsmin) THEN
c                 No lateral flame spread
              IF (time(n + 1) .GE. (tmig0 + tmb0)) THEN
c                      Burnout occurs
                 xp(n + 1) = xp0
                 xb(n + 1) = xp0
              ELSE
c                      Burnout does not occur
                 xp(n + 1) = xp0
                 xb(n + 1) = 0.
              END IF
c             Recompute ap, t and ts
              CALL Area(ap(n + 1), yp(n + 1), yb(n + 1), xp(n + 1),
     *               xb(n + 1), yp0, xp0, h, w, d, r, tmig0, tmb0,
     *               time(n + 1), xph, xbh)
```

```
            CALL Gtemp(t(n + 1), t(n), ap(n + 1), time(n + 1), hc,

     *                     xl, qfnet, qrfig,
     *                     qig, tinf, w0, h0, as, xrc, c1, tol)
            CALL Stemp(ts, t, time, dtime, 0., 0.01,xrc,tinf,tol,n,
     *                     NMAX)
         END IF

c        Compute heat release
410      CONTINUE
c          Compute the energy release rate per unit area (kW/m^2)
         qa = (hc / xl) * (qfnet + qrfig + sb * t(n + 1)**4)
c          Compute the total heat release
         q = qa * ap(n + 1) + qig
c          Has the maximum fire size been reached?
         IF ( q .GT. qmax) THEN
c              End the program
           write(1, 1000) time(n+1), yp(n+1), xp(n+1), yb(n+1),
     *     xb(n+1), ap(n+1), t(n+1), ts(n+1), q
           CLOSE(1)
           WRITE(*,*)name,' created.'
               GOTO 20
               STOP
         END IF
      END IF
      write(1, 1000) time(n+1), yp(n+1), xp(n+1), yb(n+1),
     *    xb(n+1), ap(n+1), t(n+1), ts(n+1), q
c     Continue time advance
100   CONTINUE
500   CONTINUE
      CLOSE(1)
      WRITE(*,*)name,' created.'
      GOTO 20
      STOP
1000  FORMAT(F7.2,3X,F5.2,3X,F5.3,3X,F5.3,3X,F5.3,
     *       3X,F6.3,3X,F7.2,3X,F7.2,3X,F7.1)
2000  WRITE(*,*)'ERROR -- Could not open ',name
      GOTO 20
5000  STOP
      END


c     SUBROUTINES
c     -----------

      SUBROUTINE FILE(filename,lengthfilename,extension,lengthext,name)
c     [SED]
c     This subroutine is used to create the appropriate filenames that
c     can be used by the main program for opening the .in and.out files.
      dimension filename(8)
      dimension extension(4)
      character filename,extension,name*(lengthfilename+lengthext)
        length = lengthfilename+lengthext
      j = 1
      DO 5 i=lengthfilename+1,length
      filename(i) = extension(j)
      j = j+1
```

```
    5 CONTINUE
      WRITE(name,10)(filename(I),I=1,length)
   10 FORMAT(12a1)
      RETURN
      END


      SUBROUTINE F1(f01, yp, yb, t, ts, hc, xl, qfnet, qrfig, c2, c3,
     *              qigw, xrc, tig, qf)
c     Computes RHS function of first order DE for yp
      PARAMETER (SB = 5.66E-11, PI = 3.14159)
c     Energy release rate per unit area (kW/m**2)
      qa = (hc / xl) * (qfnet + qrfig + SB * t**4)
c     Flame length (m)
      IF ( yb .LE. c2 * qigw**c3) THEN
         yf = yb + c2 * (qigw + qa * (yp - yb))**c3
      ELSE
         yf = yb + c2 * (qa * (yp - yb))**c3
      END IF
c     Ignition time (Sec.)
      tmig = (PI / 4.) * xrc * (tig - ts)**2 / qf**2
      f01 = (yf - yp) / tmig
      RETURN
      END


      SUBROUTINE F2(f02, yp, yb, t, hc, xl, qfnet, qrfig, c4)
c     Computes RHS function of first order DE for yb
      PARAMETER (SB = 5.66E-11)
      qa = (hc / xl) * (qfnet + qrfig + SB * t**4)
      tmb = c4 / qa
      f02 = (yp - yb) / tmb
      RETURN
      END


      SUBROUTINE F3(f03, ts, xrc, tig, phi)
c     Computes RHS function of first order DE for xp
      f03 = phi / (xrc * (tig - ts)**2)
      RETURN
      END


      SUBROUTINE F4(f04, xp, xb, t, hc, xl, qfnet, qrfig, c4)
c     Computes RHS function of first order DE for xb
      PARAMETER (SB = 5.66E-11)
      qa = (hc / xl) * (qfnet + qrfig + SB * t**4)
      tmb  = c4 / qa
      f04 = (xp - xb) / tmb
      RETURN
      END


      SUBROUTINE Area(ap, yp, yb, xp, xb, yp0, xp0, h, w, d, r,
     *              tmig0, tmb0, time, xph, xbh)
c     Calculates the fire growth on a wall and ceiling
c     Wall pyrolysis area with no burnout, ap1
```

```
c     Wall burnout area, ap2
      PARAMETER (PI = 3.14159)
      timeb = tmig0 + tmb0
      IF (time .LE. timeb) THEN
         IF (yp .LE. h) THEN
c           No burnout and only wall pyrolyzing
            ap1 = 2. * (yp * xp0 + (xp - xp0) * yp0 + 0.5 * (yp - yp0)
     *            * (xp - xp0))
            ap = ap1
         ELSE
c           No burnout and ceiling is pyrolyzing
            ap1 = 2. * (h * xp0 + (xp - xp0) * yp0 + 0.5 * (h - yp0) *
     *            (xp - xp0))
c           Wall ceiling jet
            zp = xp - xph
            IF (zp .GT. 0.) THEN
               apj1 = 2. * ((yp - h) * 0.08 * h + 0.5 * zp *
     *         (yp - h) - 0.5 * (0.08*h + zp) **2 *
     *         (xp-xp0)/(h-yp0))
            ELSE
               apj1 = 2. * (yp - h) * 0.08 * h
            END IF
c           Ceiling area
            apc1 = (PI / r) * (yp - h)**2
            ac1max = w * d
            apc1 = AMIN1( apc1, ac1max )
            ap = ap1 + apj1 + apc1
         END IF
      ELSE
         IF (yp .LE. h) THEN
c           Burnout and only wall is pyrolyzing
            ap1 = 2. * (yp * xp0 + (xp - xp0) * yp0 + 0.5 * (yp - yp0)
     *            * (xp - xp0))
            ap2 = 2. * (yb * xp0 + (xb - xp0) * yp0 + 0.5 * (yb - yp0)
     *            * (xb - xp0))
            ap = ap1 - ap2
         ELSE
            IF (yb .LE. h) THEN
c              Wall burnout and ceiling is pyrolyzing
               ap1 = 2. * (h * xp0 + (xp - xp0) * yp0 + 0.5 *
     *               (h - yp0) * (xp - xp0))
               ap2 = 2. * (yb * xp0 + (xb - xp0) * yp0 + 0.5 *
     *               (yb - yp0) * (xb - xp0))
c              Wall ceiling jet
               zp = xp - xph
              IF (zp .GT. 0.) THEN
               apj1 = 2. * ((yp - h) * 0.08 * h + 0.5 * zp *
     *         (yp - h) - 0.5 * (0.08*h + zp) **2 *
     *         (xp-xp0)/(h-yp0))
              ELSE
               apj1 = 2. * (yp - h) * 0.08 * h
              END IF
c              Ceiling area
               apc1 = (PI / r) * (yp - h)**2
               ac1max = w * d
               apc1 = AMIN1( apc1, ac1max )
               ap = ap1 - ap2 + apj1 + apc1
```

```
            ELSE
c              Wall and ceiling have burnout portions
               ap1 = 2. * (h * xp0 + (xp - xp0) * yp0 + 0.5 * (h - yp0)
     *               * (xp - xp0))
               ap2 = 2. * (h * xp0 + (xb - xp0) * yp0 + 0.5 * (h - yp0)
     *               * (xb - xp0))
c              Wall ceiling jet
               zp = xp - xph
              IF (zp .GT. 0.) THEN
               apj1 = 2. * ((yp - h) * 0.08 * h + 0.5 * zp *
     *         (yp - h) - 0.5 * (0.08*h + zp) **2 *
     *         (xp-xp0)/(h-yp0))
              ELSE
               apj1 = 2. * (yp - h) * 0.08 * h
              END IF
               zb = xb - xbh
              IF (zb .GT. 0.) THEN
               apj2 = 2. * ((yb - h) * 0.08 * h + 0.5 * zb *
     *              (yb -h)
     *              - 0.5 * (0.08 * h + zb)**2 * (xb - xp0)/ (h-yp0))
              ELSE
               apj2 = 2. * (yb - h) * 0.08 * h
              END IF
               ac12mx = w * d - (PI/r) * (yb - h)**2
               apc12 = (PI/r) * ((yp-h)**2 - (yb-h)**2)
               apc12 = AMIN1(apc12 , ac12mx)
               ap = ap1 - ap2 + apj1 - apj2 + apc12
            END IF
         END IF
      END IF
      RETURN
      END


      SUBROUTINE Gtemp(tn1, t, ap, time, hc, xl, qfnet, qrfig,
     *           qig, tinf, w0, h0, as, xrc, c1, tol)
c     Computes room gas temperature from correlation by iteration
        PARAMETER (SB = 5.66E-11)
      t1 = t
c     First new value of t by Gauss Siedel iteration
         qa = (hc / xl) * (qfnet + qrfig + SB * t1**4)
         q = qig + qa * ap
c     Modified to account for corner fire, coef 1.63 to 2.2
         t2 = tinf * (1.0 + 2.2 * ((q / (c1 * tinf * w0 *
     *        h0**1.5))**(2. / 3.)) * (((c1 * w0 * h0**1.5) /
     *       (as * SQRT(xrc / time)))**(1. / 3.0)))
c     estimate new value of t by Regula Falsi method
20    CONTINUE
         qa1 = (hc / xl) * (qfnet + qrfig + SB * t1**4)
         q1 = qig + qa1 * ap
         f1 = tinf * (1.0 + 2.2 * ((q1 / (c1 * tinf * w0 *
     *        h0**1.5))**(2. / 3.)) * (((c1 * w0 * h0**1.5) /
     *       (as * SQRT(xrc / time)))**(1. / 3.0))) - t1
c     new t1
         t1 =t2
         qa2 = (hc / xl) * (qfnet + qrfig + SB * t2**4)
         q2 = qig + qa2 * ap
```

```
         f2 = tinf * (1.0 + 2.2 * ((q2 / (c1 * tinf * w0 *
     *         h0**1.5))**(2. / 3.)) * (((c1 * w0 * h0**1.5) /
     *        (as * SQRT(xrc / time)))**(1. / 3.0))) - t2
c     new t2
      t2 = t1 + (t2 - t1) * ABS(f1)/( ABS(f1) + ABS(f2) )
         IF (ABS(t2 - t1) / t2 .GE. tol) THEN
            GOTO 20
         END IF
      tn1 = t2
      RETURN
      END


      SUBROUTINE Stemp(ts, t, time, dtime, qflxig, HCONV,xrc,tinf,
     *         tol, n,  NMAX)
c     Computes average room surface temperature by semi-infinite wall
c     model solving integral equation at surface by iteration
c     This version includes convection
      PARAMETER (SB = 5.66E-11, PI = 3.14159)
      DIMENSION ts(NMAX), t(NMAX), time(NMAX)
      t1 = ts(n)
      sum = 0
      IF (n .eq. 1) THEN
         sum = 0.0
      ELSE
         DO 100 j = 1, n - 1
            f1 = (qflxig + sb*(t(j)**4 - ts(j)**4)
     *           + HCONV*(t(j)-ts(j))) /
     *           sqrt(time(n + 1) - time(j))
            f2 = (qflxig + sb * (t(j + 1)**4 - ts(j + 1)**4)
     *           + HCONV*(t(j+1) - ts(j+1))) /
     *           sqrt(time(n + 1) - time(j + 1))
            sum = sum + f1 + f2
100      CONTINUE
      END IF
      f61 = qflxig + SB * (t(n)**4 - ts(n)**4)
     *      + HCONV*(t(n) - ts(n))
10    CONTINUE
      f62 = qflxig + SB * (t(n + 1)**4 - t1**4)
     *      + HCONV*(t(n+1) - t1)
      t2 = tinf + (sum * dtime / 2.0 + (f61 + f62) *
     *     sqrt(dtime)) / sqrt(PI * xrc)
      IF (ABS(t2 - t1) / t2 .GE. tol) THEN
         t1 = t2
         GOTO 10
      END IF
      ts(n + 1) = t2
      RETURN
      END
```

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A simulation model is implemented in order to predict the performance of materials in the ISO 9705 Room-Corner Test. These materials were tested by the L S Fire Laboratories of Italy, and the data they provided is analyzed in this report. A method was established to define material properties including the heat of combustion, heat of gasification, thermal inertia, ignition temperature and the total energy per unit area. These methods were developed from refinements in the theoretical model of ignition and in resolving time dependent effects in the Cone Calorimeter. The materials examined consist of some of the worst behaving since they melt, drip, expand and de-laminate from the wall and ceiling configuration of the room-corner test. Corrections have been included in the simulation modeling to account for these effects. the correction involves reducing the total energy per unit area content of the material to accordingly reduce its contribution as a wall-ceiling oriented element. An empirical correlation based on a linearized upward flame spread model is shown to provide very good correlation to the flashover time in the full-scale ISO test.

KEY WORDS (MAXIMUM OF 9; 28 CHARACTERS AND SPACES EACH; SEPARATE WITH SEMICOLONS; ALPHABETIC ORDER; CAPITALIZE ONLY PROPER NAMES)

Ceilings; Cone Calorimeters; Fire Models; Flame Resistant Materials; Flame Spread; Flashover; Ignition; Walls

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